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RECENT RESEARCHES ON THE SPECTRA OF THE PLANETS. II.[1]

By H. C. VOGEL.

JUPITER.

A PHOTOGRAPH of the spectrum of Jupiter was obtained with Spectrograph III on October 22, 1891. It extends from $\lambda 487\,\mu\mu$ to $\lambda 380\,\mu\mu$, but only fifteen Fraunhofer lines are certainly visible in this interval, as the slit was rather wide. No deviation from the solar spectrum can be detected. On October 24 of the same year an excellent photograph was obtained with Spectrograph II. The spectrum can be traced from F as far as H. It is very weak from F to $\lambda 446\,\mu\mu$, and only a few lines can be seen in this part; the violet end from $\lambda 405\,\mu\mu$ to H is also quite weak. The remaining portion of the spectrum is, however, very rich in lines; over one hundred lines in the spectrum of Jupiter can be identified with lines in the solar spectrum. I give below the observations of a small part of the spectrum which was specially investigated:

[1] Continued from page 209.

λ	
4132.3	Strong line
4134.8	Strong line
4137.0	Line
4140.2	Line
4142.3	Line
4144.0	Very strong line
4148.0	Line
4150.0	Narrow band
4152.2	Line
4154.5	System of lines
4156.8	System of lines
4159.1	Line
4161.5	Line
4164.0	Line
4165.8	Delicate line
4167.7	Strong line
4173.0	Narrow band
4178.0	Line
4182.0	Line
4185.0	Line
4187.5	Very strong line
4192.0	Strong line
4195.6	Line
4198.8	Very sharp line
4200.1	Distinct, sharp
4202.0	Sharp line

λ	
4204.0	Line
4207.0	Line
4210.5	Line
4216.0	Strong line
4217.6	Line
4219.5	Line
4222.5	Line
4224.8	Narrow band
4227.0	Very strong line
4229.9	Line
4233.5	Line
4236.0	Line
4238.2	System of lines
4240.0	System of lines
4243.0	Narrow band
4246.3	Band
4250.5	Narrow band, diffuse toward violet
4255.0	Narrow band
4260.5	Strong line
4264.3	Weak band
4268.0	Narrow band
4271.8	Strong line

In the photographs that have just been mentioned the slit of the spectrograph was placed parallel to the direction of the diurnal motion, and therefore nearly parallel to the belts; but in four photographs taken on November 1, 1894, with apparatus IV the slit was placed at right angles to the belts, in order to detect any differences of intensity between the spectrum of the strongly colored red belts and the spectra of other parts of the disk. Of the very successful photographs which were obtained, one, taken with 2^m exposure, shows about seventy lines coinciding with solar lines; the three others (two with 3^m each and one with 4^m exposure) show sixty-six lines. The two equatorial belts are very distinctly marked; they appear on the negative as bright stripes extending throughout the length of the spectrum. The

brightness of these stripes sensibly increases toward the violet, but between F and G the contrast between the spectrum of the equatorial belts and that of the adjacent parts of the disk is slight. No other difference than that of the stronger general absorption can be detected in the spectrum of the red belts.

Two of the photographs of Huggins, taken in 1878, represent the spectrum of Jupiter with that of the sky on each side. In one of the photographs the sky spectrum extends only a little beyond K, while the planetary spectrum is strong up to $\lambda 333 \mu\mu$ and can be traced as far as $\lambda 326 \mu\mu$. The weak sky spectrum allows a comparison of only the principal lines in the two spectra; comparison with the atlas showed a complete coincidence of fifty-seven planetary and Fraunhofer lines.

The second plate is not so good; only fifteen or twenty lines can be certainly recognized, which coincide perfectly with lines in the spectrum of the sky background.

A remarkable observation on the spectrum of Jupiter by Henry Draper led to the publication of an article entitled, "On a Photograph of Jupiter's Spectrum showing Evidence of Intrinsic Light from that Planet."[1] On September 27, 1879, Draper obtained a photograph of the spectrum of Jupiter with the slit placed at right angles to the direction of the belts, and on the negative was a narrow stripe running lengthwise through the spectrum nearly in the middle. The brightness of this stripe was unequal; from *h* to beyond H it was very much brighter (on the negative) than the spectrum of the neighboring parts of the disk, but below *h* it became less bright, and in the region between G and F it was even darker than the adjacent spectrum. According to the illustration which accompanies the article, the increase of brightness at *h* was very abrupt, and the deepest shade was at F. Draper attributed the stripe which ran through the spectrum to the equatorial belt, and concluded that luminous material must have been present in that region. It was not at a sufficiently high temperature, in his opinion, to emit the more refrangible rays, but it was hot enough to emit the less

[1] *M. N.* **40**, 433 (1880).

refrangible rays which, on account of the absorption of the solar rays in the equatorial regions of Jupiter, appeared bright by contrast in the lower spectrum. Draper's attention was not attracted by this peculiar spectrum until some time afterward, and he then found that the great red spot on the southern hemisphere, which at that time was the subject of much discussion, was on the middle of the disk when the photograph was taken. He therefore attributed the peculiar spectrum to this spot. "It may be that eruptions of heated gases and vapors of various composition, color and intensity of incandescence are taking place on the great planet; and a spot which would not be especially conspicuous from its tint to the eye might readily modify the spectrum in the manner spoken of above."[1]

Now, an observation of Jupiter was made on September 26, 1879, by Messrs. R. Copeland and J. G. Lohse at the Dun Echt Observatory, at a time when the red spot was also on the middle of the disk.[2] These observers, like Draper, placed the slit at right angles to the belts, in order to investigate their spectrum. They found that it was in exact agreement with my earlier observations on the belts;[3] a dark stripe extended through the spectrum from the extreme red up to $\lambda 453 \mu\mu$, the darkest part being in the vicinity of F. When the observers, after having observed the spectrum of the satellites, again investigated different parts of the disk of Jupiter, they found that the red spot on the southern hemisphere, which was then central, produced the same darkening of the spectrum as the equatorial belts. They add the following remark: "The absorption seemed to be more restricted to the region of spectrum near *b* and F than in previous observation."

This observation cannot be brought into good agreement with what is shown on the plate taken by Draper. The spectrum of the spot between G and F could not possibly be brighter than neighboring regions (darker on the negative) if in the visual spectrum the effect of the spot was such as to cause a darkening

[1] *M. N.* **40**, 435 (1880).
[2] *Ibid.*, p. 87.
[3] *Ibid.*, p. 88.

even in the "extreme red." It can only be assumed in explanation that on the following day some quite peculiar eruption from the interior of the planet had taken place, causing the spot to appear by direct observation not darker than the other parts of the disk, as it usually does, but brighter. But this assumption is contradicted by an observation made by Dr. Lohse at Potsdam, according to which the spot, although intensely red on September 27, 1879, presented in other respects the same appearance as on other days.

Hence there remains only the assumption, the probability of which is very much strengthened by the appearance of the illustration, that the cause of the peculiarity was a defect in the photographic film of the negative.

I have made repeated observations of the red spot—which in the years 1880–1883 was a remarkable object, awakening the most widespread interest—but I have never been able to find the least difference between its spectrum and that of the red belts.

With regard to the satellites of Jupiter, the spectra of which I had investigated in my early observations, there is only one observation in recent times to be mentioned. It was made at Dun Echt by Copeland and Lohse,[1] who were, however, unable to see any lines in the continuous spectrum. Their remark that a dark longitudinal stripe could be seen at times when the spectrum of the third satellite was greatly widened by means of a cylindrical lens, as if the satellite had an equatorial belt, I will mention for the sake of completeness only. No weight can be attached to the observation, since such a belt, if there were any, would not be visible if a cylindrical lens were employed. An appearance similar to that observed is also produced when the spectrum of a star is greatly widened.

On the strength of my early observations I ventured the statement that the lines in the red, which are so characteristic of the spectrum of Jupiter, were probably also present in the spectra of the satellites; this would indicate that the satellites

[1] *M. N.* 40, 88.

are surrounded by atmospheres similar to that of the primary. So far, however, no observations appear to have been made elsewhere on this subject, although with large instruments they could be made with some prospect of success.

Photographs of the spectra of the satellites have been made at Potsdam. On November 25 and 26 Mr. Wilsing obtained photographs of the spectrum of satellite III. The exposures were 20^m and 30^m. On the first plate the spectrum extends from $\lambda 487\,\mu\mu$ to $\lambda 370\,\mu\mu$; it is very strong, in the neighborhood of G even somewhat over-exposed, and shows forty Fraunhofer lines. The second plate shows forty-four lines. A number of lines also appear on photographs of the spectra of satellites I, II and IV, which were made on January 14, 1895.

SATURN.

Only one photograph of the spectrum of Saturn has been made at Potsdam. It was obtained on March 17, 1892, with 15^m exposure. The spectrum, which extends from F to $H\zeta$, is strong, and about thirty Fraunhofer lines are visible in it. The slit was rather wide, in consequence of which the fine lines are blended together into groups or bands. Narrow spaces in the spectrum near $H\gamma$ and G, and at several other places where there is an absence of lines, appear strikingly bright, and at first sight produce the effect of bright lines; but a spectrum of the Moon taken on March 5, 1892, with the same adjustment of the slit presents exactly the same appearance. No deviation from the solar spectrum can be recognized.

Two photographs were made by Huggins in 1887. One of them, taken on March 23, with an exposure of 1^h, is remarkable for the great extension of the spectrum into the ultra-violet; it can be traced as far as $\lambda 315\,\mu\mu$. The slit was wide, and therefore only twelve lines can be recognized. A photograph of less excellence, taken on March 19, with about 20^m exposure, shows only the lines $H\gamma$, G, H, K, and two groups of lines in the ultra-violet. I have also six photographs taken by Mr. and Mrs. Huggins in 1889, which have an especial interest on account of the fact that

the slit was so placed as to give the spectrum of the ansæ of the ring on each side of the spectrum of the ball. Not the least difference can be perceived between the spectra, which, on three of the plates especially, are distinctly separated.

Three of the six photographs contain little detail, and only the principal lines can be seen in the spectrum of the planet or in that of the sky background which accompanies it. A fourth plate without comparison spectrum shows twenty-two lines in the ultra-violet between H and $\lambda 344 \mu\mu$. The spectrum can be traced as far as $\lambda 330 \mu\mu$; altogether, more than thirty Fraunhofer lines can be recognized. At $H\gamma$ and H there are dark bands on the negative, which look as if they were caused by bright lines, as in the case of the Potsdam photograph. On the fifth plate they are wanting; the slit was decidedly narrower. The spectrum extends only a short distance into the ultra-violet. Altogether twenty lines are visible in the planetary spectrum, the agreement of which with the solar spectrum is complete. On the sixth plate the lines which can be identified are $H\gamma$, $\lambda 4325$, G, $H\delta$, H, K, and more than twenty lines more refrangible than K. Three lines between F and G can be seen, but not F. All lines agree with lines of the bright sky background.

In a note dated February 17, 1889, Mr. Lockyer[1] points out that in view of the hypothesis, which is becoming more and more firmly established, that the rings of Saturn are composed of small bodies of meteoric nature, it would be a matter of interest to investigate their spectrum. For, in case the collisions between the small bodies were accompanied by the evolution of gas and by the emission of light, it might be possible that some modification of the spectrum of the rings would be produced. He was led to this conjecture by the appearance of a photograph of Saturn taken by the Henry brothers, on which the brightness of the rings as compared with that of the disk of the planet was much greater than in visual observations.

As I have already mentioned, the photographs of Huggins show definitely that there is no difference between the spectrum

[1] *A. N.* 2881.

of the planet and that of the rings in the more refrangible parts of the spectrum. Lockyer's note, however, induced Mr. Keeler to investigate the spectrum of Saturn and its ring, at the Lick Observatory. His observations are published in *A.N.* 2927, and for the details of the investigation I may refer the reader to this excellent paper, in which the ideas of Lockyer are very completely refuted, and in which it is above all pointed out that the first effect of any possible self-luminosity would be to make the rings visible in the shadow of the planet.

In his investigation of the spectrum of the ring, Keeler was able to confirm an early observation of mine, which presented great difficulties on account of the small size of the image in the focus of the Bothkamp refractor. He found that in the spectrum of the ring there was no trace of the absorption band at $\lambda 618\,\mu\mu$, which is so characteristic of the spectrum of Saturn.

The greater brightness of the rings as compared with the planet, particularly for the chemically active rays, is quite naturally explained by the absence of an atmosphere around the ring and the extraordinary density of the atmosphere of the planet itself.

URANUS.

After several unsuccessful attempts Mr. Frost obtained a good photograph of the spectrum of Uranus with apparatus III on April 23, 1892. The exposure was $1^h\ 20^m$. The greatest intensity of the spectrum is between F and G, as the violet and ultra-violet rays were much weakened by absorption on account of the low altitude of the planet. The spectrum can, however, be traced as far as H; K cannot be recognized with certainty. Measurement established the presence of the following lines, the corresponding solar lines being also given for comparison:

SPECTRUM OF URANUS.		SOLAR SPECTRUM.	
λ		λ	
397:		3969	H
4101	Distinct line	4102	Strong line surrounded by delicate lines; *h*

SPECTRUM OF URANUS.		SOLAR SPECTRUM.	
λ		λ	
4135	Very weak	4133	Strong lines
4145	Very weak	4144	Strong double line
4157	Very weak and faint	4155	Group of lines
4200	Easily visible	4200	Group of rather strong lines
4240	Easily visible	4227	Strong line
4260	Narrow	4260	Double line in a group of delicate lines
4275	Broad and strong	4275	Line
		4272	Strong double line
			(With low dispersion have the effect of a broad line)
4288	Narrow band		
4291	Narrow band	4291	Group of lines
4300	Narrow band	4300	Group of lines belonging to the G group
4310	Broad diffuse band	4308	Broad G group
4320	Conspicuous dark space on the negative	4317	Nearly vacant region
4325	Broad line	4325	Strong line in a group
4341	Narrow band	4341	Strong line $H\gamma$ and group
4383	Narrow band	4384	Very strong line
444 :	Rather broad band	4443	Several lines
446 :	Rather broad band	4458	Extended group of lines

A successful photograph of the spectrum of Uranus made by Mr. and Mrs. Huggins on June 3, 1889, with 2^m exposure,[1] extends farther into the ultra-violet than the one made at Potsdam. On this plate the maximum intensity is at G. There is a very beautiful sky spectrum, full of detail, on each side of the planetary spectrum, obtained by an exposure on the following morning with a considerably narrower slit. Although no direct comparison can be made with the planetary spectrum on this account, very desirable reference points are obtained.

The measurements of these plates which I have made give the following wave-lengths of the lines, or of the bands caused by blending of groups of lines in consequence of the rather wide slit. Here also I have added the wave-lengths of the corresponding solar lines:

[1] *Sic.* (2 hours ?).—Ed.

SPECTRUM OF URANUS.		SOLAR SPECTRUM.	
λ		λ	
3565	Band } Scarcely visible	3567	Group of lines
3580	Broad band }	3584	Group of broad lines
363:	Band	3625	Middle of a broad band consisting of several systems of lines
3725 }		3722	Group of strong lines
3737 }	Lines, just visible	3736	Group of strong lines
3750 }		3748	Group of strong lines
3795	Band	3795	Group of strong lines
3833	Broad band	3833	Group of strong lines
3880	Weak band	3879	Strong line in a group of rather strong lines
3935	Broad bright band (on negative)	3934	K
3972	Broad bright band (on negative)	3969	H
4101	Distinct line	4102	Strong line; *h*
4305	Broad band, diffuse toward violet	4305	Middle of the group G
4322		4325	Strong line in a group
4340		4341	Strong line $H\gamma$ and group
486:		4862	F

The two photographs taken in Potsdam and in London supplement each other admirably, and together furnish a proof that the more refrangible portion of the spectrum of Uranus contains neither absorption bands nor bright lines; hence the assertion of Lockyer[1] that the spectrum of Uranus is to be regarded as an emission spectrum is entirely without foundation.

The careful investigation of the visual spectrum which was made by Mr. Keeler[2] with the 36-inch refractor of the Lick Observatory is in perfect accordance with this result. He expressly mentions that when he first looked at the spectrum the brightness of certain places in the yellow and green with low dispersion was such as to produce the effect of self-luminosity; but further investigation with different spectroscopes convinced him that this impression was illusory, and due to the contrast of the bright places in the continuous spectrum with the neighboring dark absorption bands.

[1] *A. N.* 2904. [2] *A. N.* 2927.

Mr. Keeler was able to see the continuous spectra of the two outer satellites of Uranus.

I extract from this paper the description of the spectrum of Uranus, and give for comparison an abstract of my earlier observations, omitting from the latter some rather uncertain details. To the very excellent representation of the visual spectrum which accompanies Keeler's article I desire to call special attention. It corresponds perfectly with the appearance in the spectroscope, and is in so far to be preferred to the drawing given in my oft-mentioned memoir on planetary spectra that it takes into account the compression of the prismatic spectrum toward the red, and therefore more nearly represents the appearance with a prism spectroscope. Considering the extreme difficulty of the object the agreement of the drawings, as well as that of the following measurements, is very good:

KEELER.		VOGEL.	
λ		λ	
6182	Middle of an absorption band which seems to be the strongest in the spectrum. With the narrowest slit that could be used the breadth of this band was but little altered, showing that it is really a broad band like the corresponding bands in the spectra of Jupiter and Saturn.	6180	Darkest place of an absorption band the breadth of which is from 5 to 6 μμ. (Somewhat less conspicuous than the band at λ 543 μμ.)
6085	(Brightest place in the red.)		
5961	Dark absorption band which narrows with the slit and is therefore a comparatively sharp line.	5961	Rather weak, narrow band.
5868	(Brightest part of the spectrum, in the yellow.)		
5768	Darkest part of a broad absorption band with ill-defined borders. The middle of the band is farther up in the spectrum, at about λ 575 μμ, and at this place there is a slight increase in brightness. The band has the appearance of being made up of several smaller ones. It is better defined on the lower than on the upper side.	5738	Darkest place of an absorption band which is diffuse on both sides, although somewhat more definitely bounded toward the red. The breadth is 10 μμ. (Not quite so dark as the band at λ 618 μμ.) *Remark.*—According to Keeler's measurement the band is identical with the telluric group δ.

KEELER.		VOGEL.	
λ		λ	
564:	(Bright place in the green).	558:	Weak line.
552	(Another bright place in the green. Between these two places there is a faint shade).		
5425	Middle of a great absorption band almost as dark as that at λ 618 μμ, but somewhat broader, and with edges not so well defined.	5425	Middle of a broad absorption band the width of which is about 5 μμ; somewhat diffuse toward the violet. The most conspicuous absorption band in the spectrum.
518:	Very faint band; position estimated. Perhaps the *b* group of the solar spectrum.		
509:	Another very faint band; position estimated.	508:	Weak band.
4850	Decided band, but dim with high dispersion. Probably at the place of F (λ 4862) but too strong for a solar line, and without doubt due to absorption in the atmosphere of Uranus.	4861	Band, or broad diffuse band.

ON THE PERIODIC CHANGES OF THE VARIABLE STAR Z HERCULIS.

By N. C. Dunér.

Toward the end of July, 1894, Mr. Chandler discovered that the star BD. + 15°3311, whose place for 1900.0 is

$$\alpha = 17^h\ 53^m\ 36^s.06, \quad \delta = +15^\circ\ 8'\ 47''.2,$$

is a variable of the Algol type, and he found its period to be $3^d\ 23^h\ 50^m$. Circumstances prevented him, however, from observing the star except when its light was increasing, and he therefore communicated his discovery to a number of European astronomers, among them the writer, in order that if possible more complete observations might be obtained. I received Mr. Chandler's ephemeris on September 12, but on account of unfavorable weather I was unable to observe a minimum until September 18. In the mean time (on the 15th) a telegram arrived from Professor Hartwig, announcing that he had discovered the variability of the same star, and that its period was $1^d\ 23^h\ 55^m\ 40^s$. This simultaneous, independent discovery by two different persons would certainly have been very surprising, if both of them had not mentioned that their attention had been directed to this star by a note in the admirable Photometric Durchmusterung of Messrs. Müller and Kempf, in which it is stated (p. 482) that the star is of a suspicious character and requires further watching.

In consequence of Professor Hartwig's telegram I resumed observation of the star on September 20, when the sky was again clear and, in fact, determined a minimum epoch. But while the star sank on the 18th more than a whole magnitude below its usual brightness, on the 20th the reduction of light at minimum was not half a magnitude; and instead of occurring a few minutes earlier than on the 18th, as the information received from both discoverers led me to expect, the minimum was

early by a whole hour. On the strength of this observation I sent the following telegram to Professor Krüger on February 21:

"The new variable is probably of the Y Cygni type, with unequally bright components. Faint and very bright minima alternate; periods 47 and 49 hours."

Further observations have shown, as I will explain fully below, that these words still represent the facts, as far as they are known, with very considerable exactness.

On September 20 and 21 Professor Hartwig wrote to Professor Krüger with reference to his discovery of the variability of the star and his researches on its periodic changes. Hartwig, like myself, found an analogy with Y Cygni, but it was evident that he had not obtained complete observations of the uneven minima, and hence regarded the analogy as perfect; *i. e.*, he believed the components to be equally bright, and hence was led to assume that the uneven minima occurred 52 hours before the even ones. My observations of September 20 and 24 show, however, that my views as stated above are correct. On all three days at the beginning of observation (*i. e.*, fully three hours before daylight, when the even minima occurred) I have seen Z Herculis brighter than BD. + 14° 3378 and found that its light was diminishing toward a minimum two hours later. If the secondary minimum occurs four hours earlier than the principal minimum, Z Herculis should have been only a little brighter than BD. + 15° 3301, or perhaps about as bright as BD. + 15° 3309, at the time when my observations began.

Some time after this Herr Lindemann, of Pulkowa, announced his opinion that the principal minimum is double, so that two minima, separated by a minimum of less pronounced character, occur in the course of an hour. I have carefully studied the observations of Herr Lindemann, but I cannot share his opinion, for the quite numerous observations which have been made by several European astronomers according to Argelander's method do not show any such depression in the light curve, and Linde-

mann's observations themselves by no means support this hypothesis in an unqualified manner. Thus, if simple curves of the ordinary form are drawn, it will be found that they represent all of the two days' observations quite well, with the exception of a single measurement (the next to the last on the second day), which shows a discrepancy of 0.4 magnitude. No other observation differs from the curve by more than 0.2 magnitude, and even such discrepancies as this occur very rarely and are not at all systematically distributed.

The minima which I have myself been able to observe are as follows:

Epoch	Minimum, Greenwich M. T.	Brightness	Remarks
0	Sept. $18^d\ 8^h\ 44^m$	7.0	Good
1	" 20 7 18	14.0	Very good
3	" 24 7 5	15.0	Good
6	" 30 7 59	6.0	Very good
8	Oct. 4 8 32	4.6	Good
12	" 12 7 54	....	Quite uncertain
18	" 24 7 9	4.0	Rather uncertain
36	Nov. 29 5 22	4.0	Fairly certain
37	Dec. 1 4 33	13.8	Quite good

The extremely bad weather in October and November interfered very greatly with the observations.

In order to derive elements from all the observations so far published, I first of all determined the following approximate elements from my own observations of the even epochs:

$$\text{Min.} = 1894.0 + 261^d.37 + 3^d.992\ \frac{E}{2}.$$

I then expressed all observations of the even epochs in days and fractions of a day, reduced them to the Sun and compared them with the above elements. In doing this I was, however, unable to avail myself of Chandler's observations, as they have not yet been published. The following results were obtained:

E.	Greenwich M. T.	Obs.—Comp.	Observer
− 2	257^d.372	− 0^d.006	H.
0	261 .342	− 0 .028	H.
0	261 .360	− 0 .010	Pann.
0	261 .360	− 0 .010	Prag
0	261 .364	− 0 .006	D.
2	265 .355	− 0 .007	Pann.
4	269 .354	0 .000	H.
6	273 .348	+ 0 .002	H.
6	273 .332	− 0 .014	D.
6	273 .333	− 0 .013	Pl.
6	273 .323	− 0 .023	Li.
8	277 .355	+ 0 .017	D.
12	285 .327	+ 0 .005	D.
16	293 .279	− 0 .027	Li.
18	297 .296	− 0 .002	D.
36	333 .220	− 0 .006	D.

In the column "Observer," D. stands for Dunér, H. for Hartwig, Li. for Lindemann, Pann. for Pannekock, Pl. for Plassmann, and Prag for the observers Gruss and Láska at that place. The above differences between observation and computation have been combined to form normal differences in the manner indicated by the horizontal lines; but in so doing Hartwig's second observation was rejected, as Hartwig himself notes that the atmospheric conditions on that day were extremely bad. No considerable effect on the result would be produced, however, if this observation were included. I have given my observations of the 12th and 18th minima only one-fourth the weight of Lindemann's, since both were observed on only one side of the light curve, and the first, in particular, was very uncertain. In this way the following equations of condition were obtained:

$$\begin{aligned} x &= -0.008 \\ x + 3y &= -0.001 \\ x + 8y &= -0.017 \\ x + 18y &= -0.006 \end{aligned}$$

From these equations I obtained the following corrected elements:

Even Epochs. $\text{Min.} = 1894.0 + 261^d.361 + 3^d.99201 \frac{E}{2}$.

The residual errors are exhibited below:

E.	Obs.—Comp.	Observer	E.	Obs.—Comp.	Observer
− 2	+ 0^d.003	H.	6	− 0^d.005	D.
0	− 0 .019	H.	6	− 0 .004	Pl.
0	− 0 .001	Pann.	6	− 0 .014	Li.
0	− 0 .001	Prag	8	+ 0 .026	D.
0	+ 0 .003	D.	12	+ 0 .014	D.
2	+ 0 .002	Pann.	16	− 0 .018	Li.
4	+ 0 .009	H.	18	+ 0 .007	D.
6	+ 0 .011	H.	36	+ 0 .003	D.

Only three uneven minima have so far been observed, all of them by me. I have not used them for determining the period, partly on this account, and partly because the small amount of the whole change during these minima renders the determination of the epochs quite uncertain. The following elements are therefore determined with reference to the period which was found for the even epochs:

Uneven Epochs. $\text{Min.} = 1894.0 + 263^d.312 + 3^d.99201 \frac{E-1}{2}$.

The observations are thus represented:

E.	Min.	Obs.—Comp.
1	263^d.304	−0^d.008
3	267 .295	−0 .009
37	335 .186	+0 .018

From the two systems of elements I have computed the following ephemeris:

EPHEMERIS OF Z HERCULIS.

E.	Even Epochs.				E.	Uneven Epochs.			
100	1895, April	5^d	23^h	4^m	101	1895, April	7^d	21^h	45^m
120	May	15	21	10	121	May	17	19	51
140	June	24	19	15	141	June	26	17	56
160	August	3	17	19	161	August	5	16	1
180	September	12	15	24	181	September	14	14	6
200	October	22	13	29	201	October	24	12	10

In the above ephemeris, as elsewhere in this article, Greenwich mean time is understood.

It will be seen at once that the star cannot be observed in Europe in 1895. On the other hand, observations can be made under favorable circumstances in America—at the California

observatories as early as the beginning of spring. The star is one of the very greatest interest, and it is greatly to be wished that it may be diligently observed, all the more because in 1896 observations can probably be made only in Asia and Australia.

Here I might close this article; but the temptation to enter into some speculations on the probable constitution of the system of bodies which compose the star is too strong to be resisted. Z Herculis occupies a unique position among the stars of the Algol type, inasmuch as its minima are of different degrees of brightness, regularly alternating between faint and very bright. As we now know that the interval between a bright and a faint minimum is greater than that between the latter and the next bright minimum, there can be no doubt that Z Herculis belongs to the Y Cygni type, and that the system does not, like Algol, consist of a bright and a dark body, but of two bodies, both of which are bright. But contrary to the case of Y Cygni, one component must be brighter than the other. The observations which are available suffice not only to determine the relative magnitudes of the two components, but also their relative brightness per unit of surface.

Herr Lindemann determined the magnitude of the star at its usual brightness and also at the time of a principal minimum, and found it to be

$$\begin{aligned} &\text{At maximum} &&= 6^{m}.89, \\ &\text{At principal minimum} &&= 8\ .05, \end{aligned}$$

and with these data I find that the magnitude is

$$\text{At secondary minimum} = 7^{m}.35.$$

The relative degrees of brightness at maximum, uneven minimum and even minimum, are as

$$1 : \tfrac{2}{3} : \tfrac{1}{3}.$$

If we let

A = the surface of the brighter star,
xA = the surface of the fainter star,
1 = the brightness of the unit surface of the first star,
y = the brightness of the unit surface of the second star,

the total brightness of Z Herculis at maximum, uneven and even minima respectively, will be represented by the following equations:

$$A+Axy = 1,$$
$$A = 2/3,$$
$$A-Ax+Axy = 1/3.$$

Subtracting the third from the first equation we obtain

$$Ax = 2/3,$$

and combining this with the second equation,

$$x = 1,$$
$$y = 1/2.$$

Hence Z Herculis consists of two components of equal size, one of which is twice as bright as the other. It is here assumed that the mutual eclipses are central, or nearly so; still I have not been able to hit upon any other assumption that represents the observations satisfactorily.

Still further conclusions can be drawn from my observations. Thus, observations extending through a whole period show that near the time of a principal minimum the variation of light extends over 6.6 hours, while near the time of a secondary minimum the entire variation requires only 4.0 hours. The orbits of the stars must therefore be considerably eccentric, and the bright minimum falls nearer to the perihelion, the faint minimum nearer to the aphelion.

If we assume that the bright minimum falls exactly at perihelion, and the faint minimum exactly at aphelion, we can determine the eccentricity of the orbit; for we have for perihelion and aphelion respectively,

$$r_1 dv = \frac{a\cos\phi}{1-e} dM,$$

$$r_2 dv_2 = \frac{a\cos\phi}{1+e} dM,$$

or,

$$\frac{r_1 dv_1}{r_2 dv_2} = \frac{1+e}{1-e}.$$

Now $\frac{r_1 dv_1}{r_2 dv_2}$ is the ratio of the arcs described by the two bodies in a unit of time, or, under the assumption which has been made, the ratio of the durations of eclipse at the even and uneven minima. Hence,

$$\frac{1+e}{1-e} = \frac{6.6}{4.0},$$

from which $e=0.245$, this value of e being the lower limit of eccentricity.

According to our elements the minima of the epochs 0, 1, 2 occur at the following times:

E.	Min.	Diff.
0	$261^d.361$	
		$+1^d.951$
1	263 .312	
		$+2$ .041
2	265 .353	

It is therefore clear that the minima do not fall exactly at the perihelion and aphelion points, as in that case the above differences would be equal, but it is also clear that they must fall very close to these points. With the aid of the above differences the angle between the line of apsides and the line of sight can be found tentatively. After several trials I have assumed that

$$e=0.2475.$$

As the line of sight must evidently pass through both stars at the epochs of both minima, the true anomalies must then be respectively v_1 and $v_2=180^\circ+v_1$.

Hence, giving v_1 some hypothetical value, the mean anomalies M_1 and M_2 can be determined by the formulæ

$$\tan \tfrac{1}{2} E = \tan \tfrac{1}{2} v \sqrt{\frac{1-e}{1+e}},$$

$$M=E-e \sin E.$$

Now, since the interval between the epochs 0 and 1 is 1.951 days, and that between 1 and 2 is 2.041 days, it is evident that aphelion occurs during the latter interval. Hence M_2 must be numerically greater than M_1, and v_2 numerically greater than v_1. We have then

$$M_2-M_1=\frac{2.041}{1.951+2.041}.360^\circ=184^\circ.06.$$

The assumed value v_1 is correct if the values of M_2 and M_1 found by it differ by $184^\circ.06$. After several trials I found:

$$v_1=3^\circ.98, \quad v_2=183^\circ.98,$$
$$E_1=3\ .09, \quad E_2=185\ .02,$$
$$M_1=2\ .33, \quad M_2=186\ .39,$$

which exactly fulfil the required conditions.

Finally, we must ascertain whether the assumed value of e is sufficiently accurate. For this purpose we first compute, with the aid of the values of M_1 and M_2 just found and the durations of the two minima, the mean anomalies M_1', M_1'' respectively at the beginning and at the end of the even minima, and the corresponding values M_2', M_2'' for the uneven minima. From these we deduce the corresponding true anomalies v_1', v_1'', v_2', v_2'', and finally the linear values, corresponding to these anomalies, of

$$r_1' \sin(v_1 - v_1'), \quad r_1'' \sin(v_1'' - v_1), \quad r_2' \sin(v_2 - v_2'), \quad r_2'' \sin(v_2'' - v_2).$$

Then, if the assumed e is correct, these last four values must be equal, since the stars are practically at an infinite distance.

The durations of the minima found above were

For even minima, $6^h\ 36^m = 0^d.27500$,
For uneven minima, $4\ \ 0 = 0.16667$.

Hence

$$M_1'' - M_1' = \frac{0.16667}{3.99201} \cdot 360^\circ = 15^\circ.03,$$

$$M_2'' - M_2' = \frac{0.27500}{3.99201} \cdot 360^\circ = 24^\circ.80;$$

$$M_1' = -5^\circ.18 \qquad M_1'' = 9^\circ.85$$
$$M_2' = 173.99 \qquad M_2'' = 198.79$$

from which we obtain:

$v_1' = -8^\circ.85$, $v_1'' = +16^\circ.76$, $\log r_1' = 9.87753$, $\log r_1'' = 9.88018$,
$v_2' = 176.26$, $v_2'' = 191.76$, $\log r_2' = 0.09574$, $\log r_2'' = 0.09306$,
$r_1' \sin(v_1 - v_1') = 0.1675$, $r_1'' \sin(v_1'' - v_1) = 0.1679$,
$r_2' \sin(v_2 - v_2') = 0.1675$, $r_2'' \sin(v_2'' - v_2) = 0.1677$.

This agreement is far more complete than is necessary, since even the third decimal may be uncertain by several units. The eccentricity which we have found is somewhat uncertain in consequence of this fact, but an eccentricity less than 0.2 or greater than 0.3 does not seem to me to harmonize with my observations.

The linear values derived above are evidently equal to the diameter of the stars expressed in terms of the major axis of the orbit.

Collecting what has been ascertained in the preceding investigation with respect to the constitution of Z Herculis, we have the following result:

Z Herculis consists of two stars of equal size, one of which is twice as bright as the other. These stars revolve around their center of gravity in an elliptical orbit whose semi-axis major is six times the diameter of the stars.[1] *The plane of the orbit passes through the Sun, the eccentricity is 0.2475, and the line of apsides is inclined at an angle of 4° to the line of sight. The stars revolve in this orbit in 3 days, 23 hours, 48 minutes, 30 seconds.*

Hence Z Herculis stands in an isolated position among stars of the Algol type, or rather it forms a hitherto missing link between the stars of the pure Algol type and Y Cygni. As I have already remarked, it is highly desirable that the star should be diligently observed by American astronomers during the present year. The last part of the above investigation shows, moreover, that it is not enough to make a large number of observations for determining the minimum epochs; the duration of the light-changes is of equal importance and should be determined as sharply as possible. Hence, when circumstances permit, the observations should begin while the star is still at its full brightness, and continue until full brightness is again restored. Accurate photometric measurements should also be made of the magnitude at maximum, as well as at both minimum epochs. The above investigation shows how much respecting the nature of the star such observations would reveal; at the same time I would be the first to acknowledge that the numerical data I have employed are greatly in need of revision, and that it will be necessary to wait for observations made under favorable conditions[2] before we can draw trustworthy conclusions as to the numerical relations of the system. These observations should moreover be made very soon. At present the angle between the line of apsides and the line of sight is small. But judging by the case of Y Cygni, we may expect that this angle is subject to rapid changes. No opportunity should therefore be neglected to determine this element as soon and as well as possible.

[1] It is here assumed that one star remains fixed in the focus of the ellipse.

[2] The conditions were very unfavorable here in 1894.

PRELIMINARY TABLE OF SOLAR SPECTRUM WAVE-LENGTHS. IV.

By HENRY A. ROWLAND.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4266.233		000	4272.114		1 N
4266.374	Ti	00	4272.299		000 N
4266.586		00 N	4272.458		0 N
4266.778		0	4272.590		00
4266.894	Cr	0	4272.701	Ti-	1
4267.122	Fe	3	4272.869		000
4267.291		000 N	4273.049		1 d?
4267.439		000	4273.274		00 N
4267.543		2 N	4273.482	Fe	3 N
4267.741		00	4273.643	Zr	2 N
4267.900		1	4273.835		00
(4267.950) s			4273.946		0
4267.985	Fe	3	4274.045	Fe?	1
4268.138	Zr	0	4274.096		1
4268.266		1 N	4274.348		2 N
4268.449		000 N	4274.542		00 N
4268.606		000 N	4274.746	Ti	2
4268.783		0	4274.958 s	Cr	7 d?
4268.915	Fe	2	4275.115		0
4269.088		00 N	4275.262		00
4269.202		00 N	4275.413		0 N
4269.339		000	4275.541		0 N
4269.446		0	4275.667		0000
4269.625	La	0	4275.713		0
4269.746		00	4275.814		0
4269.898		2	4275.866		0
4270.016		2 N	4276.050		000 N
4270.120		00	4276.150		00 N
4270.329	Ti-	1 N	4276.259		0
4270.485		00	4276.428		0
4270.649		00 N	4276.587	Ti	0
4270.880		00 N	4276.685		000
4271.112		0000 N	4276.836	-Zr	2
4271.212		0 N	4276.979		000
4271.325	Fe	6	4277.147	V-	1 N
4271.538		0	4277.384		1 N
4271.618		00	4277.544	Zr	0
4271.715		00	4277.692		2 d?
4271.790		0 N d?	4277.835		00
4271.934 s	Fe	15	4277.968		0000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4278.060		0000	4285.605	Fe	3
4278.153		0000	4285.692		1
4278.308		0	4285.834		000
4278.390	Fe-Ti	3	4285.966		1
4278.595		00 N	4286.092		00
4278.704		0000	4286.168	Ti-	2
4278.843		00	4286.244		0
4279.009	Ti-	1 N	4286.350		1
4279.225		1 N	4286.478		000
4279.380		000 N	4286.627		3 N
4279.475		000 N	4286.741		00
4279.643		2	4286.893		000
4279.874		2 N d?	4287.034		1
4280.027		1	4287.159	La	2
4280.194		1	4287.205		0
4280.374		1	4287.394		00 N d?
4280.494		000	4287.566	Ti	1
4280.556	Cr	1	4287.736		00
4280.647		000	4287.873		000
4280.698		0	4288.038	Ti	2
4280.789		0	4288.149	Ni	1
4280.938		1	4288.310	Ti	1
4281.113		1	4288.423		0000
4281.257	Mn	2	4288.562		00 N d?
4281.410		000	4288.721		0000
4281.530	Ti	0	4288.888		00 N
4281.648		000	4289.115		1
4281.752		00	4289.237	Ti	2
4281.903		000 N d?	4289.365		0000
4282.127		2 N	4289.525 s	Ca	4
4282.370		00	4289.695		000
4282.565	Fe	5	4289.885 s	Cr	5
4282.732		000	4290.080	Ti	1
4282.860	Ti	0	4290.213		00
4282.952		0	4290.377	Ti	2
4283.169 s	Ca	4	4290.542	Fe	1
4283.414	Ba?	00 N	4290.728		000
4283.565		00	4290.864		000
4283.705		000	4291.035		1
4283.905		000	4291.114	Ti	3
4284.057		000 N	4291.174		00 N
4284.223	Mn, V	0	4291.276	Ti	2
4284.382		2 N d?	4291.375		1
4284.565		0	4291.630	Fe	2
4284.689		00	4291.776		000 N
4284.838	Ni	1	4291.896		00 N
4284.990		1	4291.998		00 N
4285.164	Ti-	2	4292.135	Cr, V	0
4285.357		00	4292.208		1
4285.525		1	4292.290		2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4292.450		2	4299.846		00
4292.616		0000	4299.989		1 N
4292.739		000	4300.135		0
4292.827		0000	4300.211	Ti	3
4292.940		0000	4300.376	Mn	0
4293.035		0000	4300.478		1 N
4293.192 } s		2	4300.732	Ti	2
4293.273 }		3	4300.895		0
4293.486		000 N	4300.987		1
4293.714	Cr	00	4301.158	Ti	2
4293.817		000	4301.262		4
4293.957		0	4301.332		1
4294.077		000	4301.442		0
4294.204	Ti	2	4301.658		0 N
4294.301	Fe	5	4301.902		0 N d?
4294.531		00	4302.085	Ti	2
4294.781	W	00 N d?	4302.238		00
4294.936	Zr	2	4302.353	Fe	2
4295.015		0000	4302.460		2
4295.194		3 d?	4302.692 s	Ca	4
4295.383		3 N d?	4302.913		2 N
4295.578		000	4303.072		1 N
4295.747		000	4303.247		0
4295.914	Cr, Ti	2	4303.337		2
4296.044	Ni	1	4303.584		1 N
4296.235	La	0 N	4303.754		1
4296.375		0 N	4303.880		0
4296.548		000 N	4303.992		2
4296.735		3	4304.098		4
4296.840	Zr?	1	4304.300		00
4296.933		0 N	4304.415		1
4297.110		2	4304.552		1
4297.202	Cr	1	4304.729		2
4297.369		2	4304.882	Zr	0
4297.448		2	4305.013		0 N
4297.684		1 N	4305.266		1
4297.908	Cr, V	0	4305.377		0
4298.136	Ti	1	4305.479		1
4298.195	Fe	2	4305.614	Fe, Sr, Ti, Cr	3
4298.355		1	4305.772		000
4298.531		000	4305.871		2
4298.675	Ni	00	4306.006		1
4298.828	Ti	2	4306.078 s	Ti	4
4298.967		2	4306.305		2 N
4299.149 s	Ca	3	4306.521		00 N
4299.296		1	4306.758		0
4299.410	Ti, Fe	4	4306.858		2
4299.524		0	4307.017		2
4299.641		0	4307.215		000 Nd?
4299.803	Ti	2	4307.342		000

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4307.465		2 N	4314.673		0 N
4307.720		2 N d?	4314.894		00
4307.907 } s G	Ca	3	4314.964	Ti	1
4308.081 }	Fe	6	4315.138	Ti	3
4308.206		0	4315.262	Fe	4
4308.334		1	4315.446		000 N
4308.449		00	4315.626		00 N
4308.541		00	4315.769		00 N
4308.601		00	4315.901		0000
4308.759		2 N d?	4316.032		000
4308.937		000	4316.115		00
4309.063		1	4316.246		00 N
4309.198	Fe	2	4316.720		000 N
4309.290		0	4316.832		000
4309.365		0	4316.962	Ti?	1
4309.541	Fe	3	4317.125		0
4309.621		1	4317.226		0
4309.792		1	4317.484	Zr	0 N
4309.876		1	4317.618		000
4309.993		0	4317.883		0 N
4310.066		0	4318.064		00 N
4310.266		2	4318.232		0 N
4310.388		1	4318.369		00
4310.540		2	4318.522		0 N d?
4310.631		1	4318.631		000
4310.722		0	4318.817 s	Ca, Mn?	4
4310.862		2 N	4318.960		00
4311.058		1	4319.099		00
4311.146		1	4319.252		000 N
4311.328		2	4319.455		000 N
4311.486		00	4319.615		0
4311.608		2	4319.799	Cr	0
4311.674		2	4319.969		000 N
4311.880		2 N	4320.140		00 N
4312.050		00	4320.318		00
4312.247		2	4320.535		0
4312.311		1	4320.661		0
4312.462		2	4320.756		00
4312.665		00	4320.907	Sc	3
4312.723	Mn	1 N	4321.119		2
4312.871		0	4321.294		00
4313.034	Ti	3	4321.395		00
4313.193		1 N	4321.583		0 N
4313.399		00 N	4321.678		0000
4313.577		00 N d?	4321.813	Ti	0
4313.797		2 N d?	4321.961	Fe	2
4314.052		00 N	4322.204		0 N
4314.248	Sc	3	4322.373		00 N
4314.381		1	4322.521		00 N
4314.479	Ti	1	4322.670	Cr	0 N

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4322.862		00 N	4330.063		00
4322.992		00 N	4330.189	V	0 N
4323.167		1	4330.405		1
4323.222		0	4330.566		0
4323.386		2 N d?	4330.609		0
4323.531		0	4330.743		000
4323.670		1	4330.866[1]	Ti, Ni	2
4323.772		0	4330.984		00
4323.872		0000	4331.119		1
4324.007		3	4331.229		00
4324.138		1	4331.402		000 Nd?
4324.246	Zr	0	4331.614		0 N
4324.340		0	4331.811	Ni	2
4324.572		2 N	4331.944		00 N
4324.775		00	4332.172		00 N
4324.886		00	4332.339		00 N
4324.977		0	4332.620		00
4325.152	Sc	4	4332.745		0 N
4325.306	Ti, Cr	1	4332.988	V	0
4325.516	Ni, Zr	1	4333.082		0
4325.648		000	4333.212		00
4325.777		1	4333.367		0 N
4325.939 s	Fe	8	4333.525		00
4326.119		1	4333.588		00
4326.213		0	4333.758		000
4326.383		0000	4333.925	La	1 N
4326.520	Ti	0	4334.063		00
4326.641		000 N	4334.174		00
4326.779		000 N	4334.228		00
4326.923	Fe	2	4334.354		00
4327.082		0 N d?	4334.407		00
4327.274	Fe	3	4334.600		000 Nd?
4327.319		00	4334.833		0
4327.479		000 N	4334.965		0
4327.616		000 N d?	4335.102	La	0
4327.961		00	4335.248		00 N
4328.080	Fe	2	4335.434		1 N d?
4328.202		00 N	4335.611		00 N
4328.365		000	4335.762		00 Nd ?
4328.446		000	4335.944		00 N
4328.598		000	4336.076		00
4328.772		0 N	4336.147		000
4329.007		00	4336.295		0000
4329.089		000	4336.433		00
4329.213		00	4336.602		000 Nd?
4329.306		0000	4336.774		00 N
4329.448		0 N	4336.951		00
4329.559		0 N	4337.034		00
4329.712		00	4337.216	Fe	5
4329.853		00	4337.414		0

[1] This is a weak, hazy Ni line. It is faintly present in a specimen of meteoric iron. The Ni line is on the red edge of the solar line and the Ti line is nearer the center.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4337.569	Mn	00	4345.506		0000
4337.725	Cr	3	4345.593		0000
4337.945	Sr?	00	4345.767		00 N
4338.084	Ti	4	4345.933		00
4338.245		000	4346.068		0 N
4338.292		00	4346.278		00
4338.430	Fe	1	4346.454		1
4338.616		0 d?	4346.580		00
4338.779		00	4346.725	Fe	2
4338.854		0	4346.835		00
4338.993		0 N	4346.987	Cr	1
4339.170		000	4347.066		0000
4339 294		0	4347.199		000
4339.416	Fe	0	4347.266		000
4339.617	Cr	4	4347.403	Fe	1
4339.882	Cr	3	4347.532		00 N
4340.070		000	4347.705		1 N
4340.192		000	4347.845		000
4340.297	Cr	0	4348.003	Fe	2
4340.634 $H\gamma$	H	20 N	4348.130		1 N
4341.007		00 N d?	4348.266		000
4341.167	V	0	4348.349		00
4341.286	Zr	0000	4348.497		1 N
4341.410		00	4348.651		00 N
4341.530	Ti?	2	4348.800		00 N
4341.723		00	4348.933		00 N
4341.880		0	4349.107	Fe	2
4341.991		0	4349.330		000 N
4342.087		0	4349.538		000
4342.219		000	4349.967		00
4342.350		0	4350.119		00 N d?
4342.482		00	4350.319		0
4342.750		000 N	4350.413		0
4343.004		000 N	4350.550	Ba?	00 N
4343.150		00 N	4350.747	Fe	0 N
4343.372 } s	Cr	2	4350.921		0000
4343.431 }	Fe	2	4351.000	Ti	1
4343.577		00 N	4351.216	Cr	3
4343.662		0 N	4351.338		00
4343.861	Fe	2	4351.464		00
4344.015		0000	4351.551		00
4344.130		1 N	4351.711	Fe	2
4344.306		00 N	4351.871		0000
4344.451	Ti-	2	4351.930	Cr	5
4344.670	Cr	4	4352.083	Mg	5 N d?
4344.830		000	4352.235		0 N
4344.906		00	4352.425		0 N
4345.052		0	4352.559		00 N
4345.246		00	4352.718		0 N
4345.399		0000	4352.908 s	Fe	4

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4353.044	V	0	4360.451		1
4353.214		000 N	4360.644	Ti	1
4353.337		00 N	4360.796		000
4353.596		00 N	4360.958	Fe, Zr	1
4353.678		00 N	4361.091		000
4353.813		00 N	4361.219		000 Nd?
4353.985		00	4361.405		00
4354.110		0	4361.474		00
4354.228		00	4361.676		0000
4354.426		0 N d?	4361.828		000
4354.597		00	4361.955	Sr?	00 N
4354.674		00	4362.021		0000
4354.776		1	4362.198		000
4354.927	Fe?	0 N	4362.262		0
4355.112		00 N	4362.387		00
4355.257	Ca?	2	4362.542		000
4355.509		0	4362.690		1
4355.578		00	4362.909		0 N
4355.746		00	4363.113		00 N
4355.867		0	4363.267	Cr	1 N
4356.058		0	4363.457		0 N
4356.163	Ni	0	4363.629		0
4356.299		00	4363.766		0
4356.414		000	4363.979		00 N
4356.528		0	4364.136		000
4356.766		0	4364.198		1
4356.901		00	4364.349		1
4357.071		0	4364.490		00
4357.223		000	4364 662		00 N
4357.312		00 N	4364.827	Ce	00
4357.457		00	4365.031		000
4357.677		0 N d?	4365.168		000
4357.865		000	4365.451		00 N
4358.033		0	4365.694		0
4358.178		00	4365.885		00 N d?
4358.328		0	4366.061	Fe	2
4358.521		00	4366.246		00 N
4358.670	Fe	2	4366.362		00 N
4358.879	Y-Zr	0	4366.572		00
4358.985		00	4366.660	Zr-	1
4359.084		00	4366.838		1
4359.236		000	4367.068		00
4359.358		00	4367.222		000
4359.500		00	4367.354		00
4359.654	Ni	0	4367.495		00
4359.784 s	Cr	3	4367.637		00
4359.907	Zr	0	4367.749	Fe	5
4360.067		00	4367.839	Ti	2
4360.150		00	4367.882		00
4360.280		0000	4368.071	Fe	2

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4368.224		00	4375.216		000
4368.291		0	4375.358		0 N d?
4368.462	Ni	0	4375.493	Cr	0
4368.629		000	4375.643		00
4368.801		0	4375.734		0
4369.052	Ti	00 N d?	4375.823		0
4369.254		00	4375.940		0000
4369.428		00	4376.107 s	Fe	6
4369.568		1	4376.381		00 N
4369.708		00 N d?	4376.572		0 N
4369.873	Ti	0	4376.727		0 N
4369.941 s	Fe	4	4376.942	Fe, Cr	1
4370.025		00	4377.113		00 N
4370.189	Ni	00	4377.254		00 N
4370.318		0	4377.388		2 N
4370.453		0	4377.533		0 d?
4370.583		00	4377.706		0
4370.743		000	4377.948	Fe	1
4370.815		00	4378.149		00 N
4371.016		000	4378.419		2 N d?
4371.144	Zr	1	4378.677		0 N d?
4371.221		1	4378.902		00 N
4371.320		00	4379.071		1 N
4371.442	Cr	2	4379.232		00 N
4371.588		0 N d?	4379.396[1]	V	4
4371.748		000	4379.565		000
4371.957		0 N	4379.691		00
4372.115		00	4379.798		000
4372.184		00	4379.927	Zr	0
4372.360		000	4380.066		000
4372.498		0 d?	4380.325	Co	2 N d?
4372.656		00	4380.395		000
4372.747		0000	4380.521		00
4372.899		0	4380.655		0
4373.008		0	4380.883		2 N d?
4373.148	Fe?	0	4381.004		00 N d?
4373.278		000	4381.146		00
4373.415	Cr	1	4381.274	Cr	0
4373.554		00 N	4381.451		00 N
4373.727	Fe	2	4381.875		00
4373.813		0000	4382.045	Mn	00
4373.949	V	0	4382.159		00
4374.055		0	4382.325		00
4374.206		000	4382.475		00 N
4374.331	Cr	1	4382.676		0
4374.384		1	4382.847	Mn	0
4374.628	Sc, Fe?	3	4382.928	Fe	2
4374.775		00 N	4383.156		0 N
4374.981	Zr	0	4383.332		00 N
4375.103	V, Mn	2	4383.468		000 N

[1] The strongest Vanadium lines in the whole solar spectrum or in this part, if not the whole, of the Vanadium spectrum.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4383.535		000 N	4390.790		0
4383.720 s	Fe	15	4390.932		00 N
4383.879		000 N	4391.002		0000
4383.990		000 N	4391.123 s	Fe	2
4384.122		000 N	4391.192 s	Ti	1
4384.284		0 N	4391.306		000
4384.477		1	4391.462		00
4384.698	Ni	0	4391.642		00
4384.873[1]	V	3	4391.824	Co	0
4384.986		0	4391.924	Cr	1
4385.144	Cr	2	4392.034	Co	0
4385.286		1	4392.235	V?	1 N
4385.406	La	1	4392.470		00 N
4385.548		2	4392.591		000 N
4385.767		00	4392.752		1
4385.833		00	4392.947		00 N
4386.016		00 N	4393.085		00
4386.221		0 N	4393.196	V?	0
4386.433		0000 N d?	4393.442		0
4386.616		0	4393.686		1 N d?
4386.750		00	4393.858		0
4386.855		00 N	4393.974	V?	0
4387.007	Ti?	1	4394.093	Ti	0
4387.220		1 N	4394.225	Ti?	2
4387.420		000 N	4394.342		00
4387.559		0	4394.463		000
4387.658	Cr	0	4394.782		000
4387.762		0	4394.943		00
4387.906		000	4395.020	Zr	00
4388.057	Fe, Co	2	4395.201	Ti	3
4388.260	Mn	00 N d?	4395.413[2]	V, Zr	2
4388.411		00 N	4395.448		00
4388.571	Fe	3	4395.665		0
4388.746		00 N	4395.843		000 N
4388.887		0	4396.008	Ti	1
4389.029		0 N	4396.224		00
4389.190		000	4396.312		00
4389.247		00	4396.471		0
4389.413	Fe-	2	4396.592		00
4389.555		000	4396.790		00 N
4389.667		0 N	4396.931		000
4389.801		0	4397.125		1 N
4389.930	Mn, Ni?	0	4397.306		00
4390.034		00	4397.428		00
4390.149[2]	V	2	4397.550		00
4390.273		000	4397.742		000 N
4390.379	Ni	00	4397.952		00 N d?
4390.496		00	4398.178	[3]	1
4390.617	Fe?	1	4398.334		00
4390.699		0	4398.460		0

[1] The strongest Vanadium lines in the whole solar spectrum or in this part, if not the whole, of the Vanadium spectrum.

[2] Very strong Vanadium lines.

[3] In Zircon but not in Zr.

Wave-length	Substance	Intensity and Character	Wave-length	Substance	Intensity and Character
4398.651		0 N	4406.997		00
4398.784		00	4407.155		00
4398.879		00	4407.297		000
4399.010		00	4407.432		0 N
4399.230		00 N	4407.533		00 N
4399.379		00	4407.680		000
4399.451	Ni	0	4407.810 } s	V	2
4399.640		00	4407.871 }	Fe	4
4399.776	Ni	0	4408.022		000
4399.935	Ti, Cr	3	4408.096		00
4400.149		00 N	4408.236		000
4400.343	Zr	0 N d?	4408.364[1]	V	2
4400.555	Sc	3	4408.582	Fe	3
4400.738	V	1	4408.683[1]	V	2
4400.844		000	4408.818		00
4401.020	Ni	0 N	4408.956		00 N
4401.183		1 N	4409.096		00 N
4401.241		000	4409.288	Fe?	1
4401.456	Fe	2	4409.408		0
4401.613	Fe	1	4409.525		00 N
4401.709	Ni	2	4409.683		1
4401.828		000	4409.853		000 N
4402.509		00 N	4410.015		000 N
4402.640		00 N	4410.168		0 N
4402.843		000 N	4410.328		00 N
4403.111		00 N	4410.463	Cr	00 N
4403.241		00	4410.683	Ni	2
4403.347		1	4410.817		000
4403.532	Cr, Zr	0	4410.923		0000
4403.661	Cr	00	4411.019		00
4403.815		00 N	4411.111		000
4403.990		00 N	4411.240	Cr-	1
4404.131		0	4411.385		00 N
4404.261		00	4411.748		00 N
4404.433	Ti	1 N	4411.882		00 N
4404.563		00	4412.043	Mn	000
4404.706		00 N	4412.092		1
4404.757		00 N	4412.297	V	00
4404.927 s	Fe	10	4412.415	Cr	0
4405.082		00	4412.581		00 N
4405.191		1	4412.861		00 N
4405.472		000	4413.042		00 N
4405.576		00	4413.280	Zr	00 N
4405.728		00 N	4413.560		00 N
4405.896		0 N d?	4413.756		1
4406.201		00	4413.944		000
4406.319		0	4414.011	Cr	0
4406.456		000	4414.207		000
4406.662		00	4414.278		00
4406.810[1]	V-	2	4414.391		00

[1] Very strong Vanadium lines.

PLATE XIV

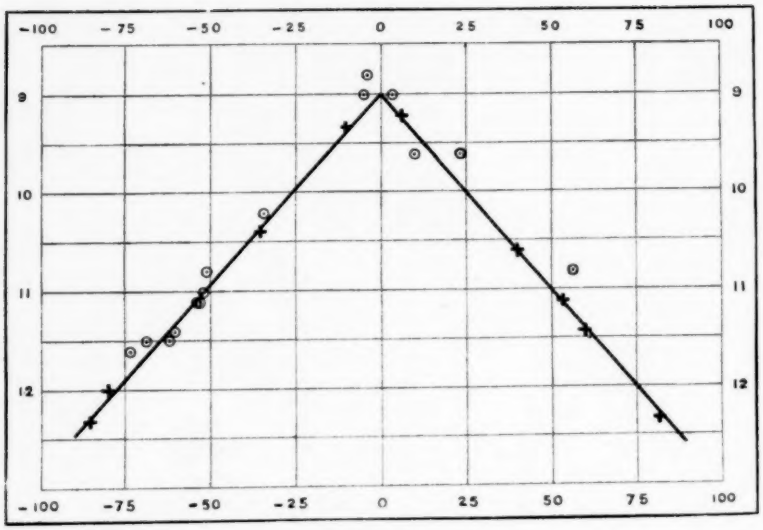


FIG. 1

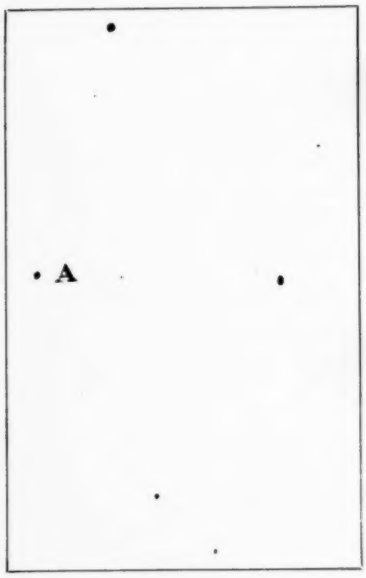


FIG. 2

FIG. 3

T ANDROMEDÆ.

By Edward C. Pickering.

On learning of the discovery by Mr. Anderson of the variable star T Andromedæ, an examination was made of the Henry Draper Memorial photographs of this object. The results were communicated to the *Astronomische Nachrichten* (**134**, 347), and, as there stated, indicate a photographic magnitude of 9.0 at maximum, and a very uniform increase and diminution in the light at the rate of one magnitude in twenty-six and twenty-five days respectively during the three months preceding and following the maxima. This form of light curve is confirmed by the photographs taken since then which are enumerated below. They also indicate a change in the period, the value 281 days, which satisfies the observations during 1891 to 1894, giving a maximum later than that which actually occurred in 1895. These results are represented in the following table, which gives in successive lines all the photographs so far obtained here of this star. Photographs of the region taken when the star was too faint to appear are not included. The dates and observed photographic magnitudes are followed by the maximum computed by the law given above. Thus the first plate was taken on the Julian Day 2,412,039. The magnitude 10.4 indicates that it was 1.4 magnitudes fainter than the maximum, and multiplying 1.4 by 26 gives 36, the time in which the maximum would be attained. Adding 36 to 2,412,039 gives 2,412,075, or 2,075 if we omit the constant 2,410,000. This quantity is entered in the third column. The mean of the individual values of each time of maximum is given in the next column, followed by the residuals found by subtracting it from the individual values. The residuals have the average value of $\pm$ 2.9 days, corresponding to a deviation of the observed magnitudes of $\pm$ 0.11. These values would be reduced one-quarter if we could reject the last three results. The latter are not due to errors of observation,

since a second independent measurement gave the same result in each case within 0.05 of a magnitude, corresponding to a change of two days in the time of maximum. While these photographs fail to show whether the light curve is pointed or rounded at the exact time of maximum, they indicate that the curvature, if any, is inappreciable except within a few days of the maximum.

Date	Obs. Mag.	Max.	Mean	Resid.
1891 Nov. 2	10.4	2075	2074	+ 1
" " 27	9.3	2072		— 2
" Dec. 13	9.2	2075		+ 1
1892 Oct. 24	10.6	2356	2356	0
" Nov. 6	11.1	2357		+ 1
" " 13	11.4	2356		0
1893 Sept. 13	12.3	2638	2638	0
1894 Jan. 2	12.3	2917	2916	+ 1
" " 7	12.0	2914		— 2
" " 7	12.0	2914		— 2
" " 19	11.5	2913		— 3
" " 25	11.5	2919		+ 3
" Feb. 2	11.1	2917		+ 1
" Sept. 28	11.6	3168	3173	— 5
" Oct. 11	11.4	3175		+ 2
" " 18	11.1	3175		+ 2
" " 19	11.0	3173		0
" " 20	10.8	3169		— 4
" Nov. 6	10.2	3170		— 3
" Dec. 5	9.0	3168		— 5
" " 6	8.8	3169		— 4
" " 13	9.0	3176		+ 3
" " 20	9.6	3168		— 5
1895 Jan. 2	9.6	3181		+ 8
" Feb. 5	10.8	3185		+ 12

The form of light curve is shown in Plate XIV, Fig. 1, in which abscissas represent the times in days preceding or following the observed maxima, and ordinates the corresponding magnitudes. The assumed law is represented by the heavy line. The observations from which the form of light curve was inferred are represented by crosses, the later observations by circles.

If we take first differences of the times of maxima found above we find the intervals 282, 282, 278 and 257. The observations during 1891 to 1894 are therefore very well satisfied by the period 281 days. The observations of 1894 indicate a change

in the period which cannot be accounted for by errors of observation. Rejecting the last two observations changes the mean time of maximum from 3173 to 3171.

The magnitudes given above are found by comparing the photographic images of the variable with adjacent comparison stars of nearly equal brightness and estimating the difference in magnitude. The comparison stars when the variable is bright are BD. + 26° 40, + 26° 47, + 25° 42 and + 25° 40. Their photographic magnitudes are 8.7, 9.2, 9.8 and 10.3. The positions and magnitudes of the fainter stars will be given elsewhere.

In a recent article in the *Astronomical Journal* (**14**, 183) Mr. P. S. Yendell describes his observations of this star and concludes that the period is 265.35 days. Since the photographic magnitudes do not accord with this theory, he derives the singular conclusion that they must be wrong, maintaining that some of them are in error by two or three magnitudes. He states that the light curve described above has a form which "is not only inherently improbable, but which actually proves to be incorrect." Inherently improbable does not seem to be a strong argument in view of the variety in form of light curves of variable stars, especially as the linear form is strikingly confirmed by Nova Aurigæ and other variables (*A. N.* **134**, 138). It also represents one of the simplest theoretical laws, the variation in the energy being proportional to the energy itself. Furthermore it coincides with Newton's law of cooling. Whether the light curve is actually incorrect cannot be proved by observations made at a different time and on a different portion of the light of the star. As Mr. Yendell does not give the light curve he has himself deduced or even the names and magnitudes of his comparison stars, it is difficult to discuss it. It may be noted, however, that unless he measured the variable photometrically or used magnitudes photometrically determined for his comparison stars, it would be impossible for him to tell whether his light curve was linear or not, when represented on the scale of Pogson used here. The error in his assumed scale of magnitudes might easily introduce a marked deviation from a straight line in his

curve. Mr. Yendell's table of observed maxima appears to me illusory. Two of these maxima are derived from the Harvard photographic magnitudes by a process which he does not describe, and give results which differ widely from those found here. It is surely impossible to infer from maxima thus obtained that the observations on which they depend are themselves sometimes in error by more than two magnitudes. If such errors exist, this determination of the maxima should have been rejected.

The photograph of this star taken on November 27, 1891, is represented in Fig. 2. The variable, A, is distinctly brighter than the two stars below and to the right, which are of about the tenth magnitude. The upper of these stars is BD. + 25° 40. A defect in the original negative to the left of this star has been removed in the print without affecting the image of the star itself. The magnitude of the variable on this day according to the above table is 9.3. The photograph taken October 24, 1892, is represented in Fig. 3. The variable, B, is here fainter than the stars below. Its magnitude is given above as 10.6, or 1.3 magnitudes fainter than A. According to Mr. Yendell's theory on the first date the photographic magnitude 9.3 is too bright by 2.1 magnitudes, and its magnitude should have been 11.4. B similarly should have been 10.5, or 0.9 magnitudes brighter than A. An inspection of the plate will enable the reader to decide whether to believe that Mr. Yendell's theory or the photographic magnitudes are in error.

HARVARD COLLEGE OBSERVATORY,
CAMBRIDGE, MASS.,
March 5, 1895.

ECLIPSE OF JUPITER'S FOURTH SATELLITE, FEBRUARY 19, 1895.

By EDWARD C. PICKERING.

PHOTOMETRIC observations of the satellites of Jupiter while undergoing eclipse have now been maintained at the Harvard College Observatory for many years. This method has special advantages in the case of the fourth satellite, owing to the slow variation in its light. The total number of eclipses of this satellite that can be observed from any one station is comparatively small. From April 16, 1892, to January 16, 1895, the satellite passed outside of the shadow of Jupiter and was not eclipsed. On January 16 Jupiter was below the horizon at Cambridge at the time of the eclipse. At the next eclipse on February 2 the night was cloudy.

On February 19, 1895, the fourth satellite was compared with the second satellite by means of a photometer consisting of a double image prism and Nicol (*Harvard Annals*, **11**, 4). Observations were made continuously from 28 minutes before to $26^m\ 42^s$ after the predicted time of disappearance, $13^h\ 23^m\ 18^s.4$ Greenwich Mean Time. Observations of the reappearance, which was predicted to occur at $14^h\ 58^m\ 52^s.0$ G. M. T., were prevented by clouds. The photometer was attached to the 15-inch telescope of the Observatory, and all of the observations were made by Mr. O. C. Wendell. In the annexed table the observations are arranged in groups in successive lines. Each group consists of twenty photometric settings, except the last, which consists of eight settings. The mean of the observed times minus the computed time of disappearance is given in the first column expressed in seconds, and the corresponding mean difference in magnitude of the fourth and second satellites in the second column. As the satellites are close together they would be equally affected by the clouds which interrupted the later observations. The deviations of the observed magnitudes

from a smooth curve, whose second differences are nearly constant, are given in the third column. The average value of these differences is only $\pm .04$ so that the form of the curve is defined within narrow limits.

Time	Obs. Mag.	O.—C.	Time	Obs. Mag.	O.—C.
-1564^s	1.00	+.05	$+202^s$	2.20	+.05
−1292	.94	−.03	+ 395	2.38	−.04
− 850	1.16	+.03	+ 606	2.74	−.01
− 612	1.24	−.04	+ 802	3.10	+.02
− 389	1.36	−.11	+1054	3.56	+.01
− 194	1.64	−.02	+1508	4.42	−.01
+ 3	1.96	+.07			

The large deviation of the time of disappearance from that given by computation, and the long duration of the variation are in part due to the obliquity with which the satellite entered the shadow of Jupiter.

HARVARD COLLEGE OBSERVATORY,
CAMBRIDGE, MASS.,
March 5, 1895.

THE SPECTRUM OF MARS.

By LEWIS E. JEWELL.

THERE has been a discussion in recent numbers of *Astronomy and Astro-Physics* between Professor Campbell and Dr. Huggins on the spectrum of Mars. As I have recently been making a careful spectroscopic study of water-vapor in the Earth's atmosphere, I have thought that some of the results bearing upon the possibility of determining the presence of water-vapor in the spectrum of Mars might be of interest.

In the investigation just referred to the quantitive values of the intensities of the lines in the spectrum of water-vapor were determined in terms of the amount of water-vapor the sunlight was required to pass through in order that the water-vapor lines might be of any given intensity. These values were determined by an indirect method, so that the absolute values may be a little too large or too small, but the relative values are correct, and the absolute values are approximately correct. I have also determined the amount of water-vapor required to make its presence visible in the spectroscope. For this purpose several spectroscopes have been used, but the results will be given for only three of these instruments. The large concave grating of 20,000 lines to the inch and twenty-one feet six inches radius gives an actual separation of the D lines of $6^{mm}.14$ at the focus of the grating in the second spectrum without any magnification.

A plane grating of 7200 lines to the inch, used with collimating lenses of six and one-half inches diameter and seven feet six inches focal length, gives a separation in the first spectrum of $0^{mm}.826$.

A Steinheil spectroscope of two 60° prisms, used with collimating lenses of one and one-half inches diameter and thirteen inches focal length, gives a separation of $0^{mm}.056$. This spectroscope shows the nickel line between the D lines, but it is difficult to see. These spectroscopes used in the manner indicated will be

referred to as the concave grating, the plane grating, and the Steinheil spectroscope.

With the concave grating an amount of water-vapor equivalent to a thickness of 0.23 inches of water can be detected; but the amount cannot be satisfactorily measured until it is equivalent to one-half or three-quarters of an inch of water. The accuracy of determinations made with this grating is largely due to the fact that the individual lines in the spectrum of water-vapor are distinctly visible, and the dispersion is so great that an extremely faint and narrow line can be detected. With the plane grating (used for this purpose only in the first spectrum) the dispersion was much less, and it was impossible to detect a line unless it was three or four times as strong as the faintest lines seen with the concave grating. By observing the intensity of the strongest line in what is known as the "rain-band" (wave-length = 5919.855) an amount of water-vapor equivalent to 0.67 inches of water can be detected; but it would require as much as one and a half or two inches to enable one to make reasonably accurate observations.

If instead of using this single line we observe the group of three prominent lines of which this line forms the red component, we are but little better off, as the violet component of this triplet is partly solar. This triplet is, however, the best group of lines for this purpose in the spectrum of water-vapor.

With the Steinheil spectroscope none of the individual lines in the spectrum of water-vapor can be seen; the triplet referred to can, however, be seen as a single line, with an amount of water-vapor equivalent to one and a half inches of water. It was, however, seen with the greatest difficulty; and no reasonably good observation can be made of the intensity of this triplet unless the sunlight has passed through an equivalent of three or four inches of water; in fact, considerably more would be required to make satisfactory estimates. If instead of observing this triplet we observe the group of lines between the wave-lengths 5914 and 5925, which Professor Campbell has called d'' we will have but little better results than with the triplet. The

region d''' contains both water-vapor and solar lines, and with a dispersion so small as to necessitate the use of this group, the presence of water-vapor cannot certainly be detected until the group of water-vapor lines is about half as intense as the group of solar lines. This group is without doubt the best one for the purpose of any of those used by Professor Campbell.

The values given are approximately correct when the Sun is used as the source of light and the definition is very good. Where a weak source of light is used, such as the Moon or the planet Mars, the quantity of water-vapor required to make its presence visible in the spectroscope, may be considerably greater than the values given.

We will now consider the amount of water-vapor present in the air during the different seasons of our own planet. We will express it by the depth of a layer of water, equivalent to the amount of water-vapor contained in the air. The amounts given in the following table are the monthly means as observed at Baltimore. I also give the amounts present upon two special occasions, *viz.*, January 10, 1893, and the mean of July, 14, 15, 16, 17 and 18, 1893.

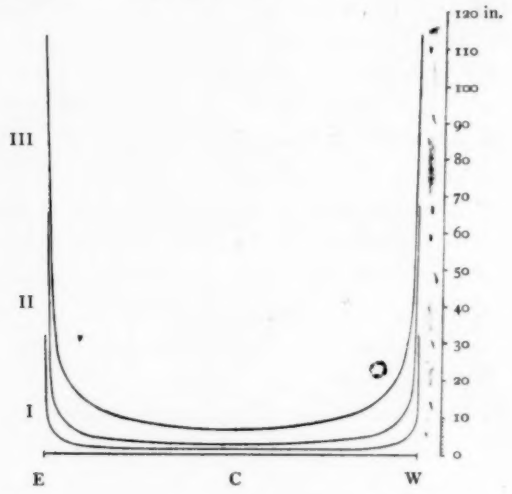
January	$0^{in}.73$	August	$2^{in}.17$
February	0 .86	September	1 .56
March	0 .95	October	1 .46
April	1 .28	November	1 .04
May	2 .17	December	0 .77
June	3 .25	January 10, 1893	0 .31
July	2 .45	July 14, 15, 16, 17, 18, 1893 (mean)	5 .40

It is perhaps well to repeat that the quantities as given in the table are only approximate, being determined by an indirect method, and the true values may be somewhat greater or less than the values given, but they are probably not far from right; and the relative amounts are fairly well determined.

To better understand what we should expect to see in the spectrum of Mars, let us imagine what we should see were we to examine the spectrum of the Earth's reflected light, from a suitable point in space. Let us suppose we are examining the Earth's spectrum with a spectroscope whose slit stretches all the

way across the image of the Earth as formed at the focus of the telescope we are using. Also, to avoid complications, let us further suppose the atmospheric conditions to be uniform over the Earth at the time, irrespective of latitude; and let us consider the Sun to be in the zenith of the place at the center of the image of the Earth.

If we suppose the atmospheric conditions to be similar to those prevailing during January (as observed at Baltimore) the



The intensity of a water-vapor line in the spectrum of the Earth's atmosphere as seen from a point in space.

I, Curve for January.
II, " " October.
III, " " June.

E and W the edges and C the center of the image of the Earth as seen in a telescope.

intensity of the water-vapor lines will vary from the center to the edges of the spectrum, as in Curve I in the accompanying figure. The conditions prevailing during October and June are represented by Curves II and III.

However, to better show the difficulties of such observations, the curves do not exactly represent the relative intensities of the lines in the spectrum of different portions of the disk, but repre-

sent the amount of water-vapor the sunlight passes through in twice traversing the air. The scale at the side gives the amount in inches of water. The slope of curves representing relative intensities would be somewhat less steep than the curves given; otherwise they would be similar.

We could detect the presence of water-vapor in the spectrum of the Earth's atmosphere if the conditions were similar to those prevailing during January in the latitude of Baltimore, providing the dispersion and definition were equal to that of the plane grating when using the Sun as the source of light. With a dispersion and definition equal to that of the Steinheil spectroscope, we could detect the presence of water-vapor in the Earth's atmosphere if the hygroscopic conditions were similar to those prevailing at Baltimore during October.

The spectrum of Mars and the Moon, as seen by Professor Campbell, seems to have been inferior in point of definition to that given by the Steinheil spectroscope used with sunlight, and the instrumental equipments of Dr. Huggins and the other observers who have worked upon the spectrum of Mars were probably much inferior to those of the Lick Observatory. As a consequence, it necessarily follows that unless the amount of water in the atmosphere of Mars is greater than that in the Earth's atmosphere in October at Baltimore, it is useless to look for the presence of water-vapor in the spectrum of Mars, unless our instrumental means are much superior to any hitherto used for that purpose. The subject is rendered much more difficult by the fact that when we examine the spectrum of Mars we are looking through a large amount of water-vapor in the Earth's atmosphere.

Professor Campbell strenuously objects to other observers making observations upon Mars when the planet's altitude is small and the humidity of the air considerable; and yet his own observations were made during those months when the air contains the greatest amount of water-vapor. He also seems to consider the relative humidity the chief factor to be considered, whereas it is the dew-point that is important. We may have a

low relative humidity during warm weather and still have a very large amount of water-vapor in the air; and we may also have a high relative humidity during cold weather and have very little water-vapor in the air. It is also well to say that the surface conditions as determined by the hygrometer are not necessarily the index of the amount of water-vapor present in the air above the surface of the Earth. At times the discrepancy is considerable. Neither is he entirely right in his estimate of the great advantages resulting from an altitude of 4200 feet in observations upon the spectrum of the planets. There is unquestionably an advantage, but it is much less than he thinks, especially during the months in which he made his observations. The distribution of water-vapor in the air is not similar to the distribution of oxygen and nitrogen. During very cold weather and in a high barometer there is some similarity, but during the warm, humid months the amount of water-vapor in the air increases with the altitude to near the height of the lower clouds, and then begins to decrease. As a consequence there is less advantage in a moderate elevation than we would expect. During very cold weather with a high barometer, however, the advantages are greater.

Unless the aqueous contents of the atmosphere of Mars are much greater than we are justified in assuming from the appearance of the planet, it seems useless to attack this problem with such spectroscopes as have hitherto been used; and instruments of greater dispersion are unsuitable because of the lack of sufficient light.

In regard to determining the presence of oxygen, however, the case is not quite so hopeless, if we make our observations at a considerable elevation with the planet near the zenith, for the B group can be readily seen with small dispersion, and the presence of oxygen in the atmosphere of Mars might possibly be detected by careful observations.

It seems to me, however, that there may be more hope of detecting the presence of chlorophyl than either oxygen or water vapor in the spectrum of Mars. Of course it will require careful

and delicate observations, but the chlorophyl band in the red end of the spectrum of vegetation is quite strong; and if the green areas of Mars are due to vegetation, this band might be seen.

In speaking about this matter with Professor W. H. Pickering a few weeks ago, I asked him why no one had looked for this band, and he informed me that he had looked for it, but that the season on Mars was so far advanced at the time that the areas that had been of a strong green color had become gray at the time his observations were made, so that they were not conclusive.

If the green areas upon Mars are due to vegetation, and the ruddy areas similar to the desert regions of the Earth, the chloryphyl band ought to be recognized by its presence in the spectrum of one area and its absence in the other.

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ON A NEW METHOD OF MAPPING THE SOLAR CORONA WITHOUT AN ECLIPSE.

By GEORGE E. HALE.

IN the October (1894) number of *Astronomy and Astro-Physics* I described the various methods that have been employed for the purpose of observing the corona without an eclipse. Unfortunately, I was unable to show that any measure of success had attended the numerous investigations conducted with this end in view, nor was it possible to conclude the paper with the expression of any very confident hope of an early solution of the problem.

An account of Professor Riccò's experiments with the spectroheliograph which I had left on Mount Etna was published in the January number of THE ASTROPHYSICAL JOURNAL. In spite of the fact that the atmospheric conditions enjoyed by Professor Riccò were certainly excellent, the method failed of success. The coronal forms shown on the best negatives obtained are probably of atmospheric origin. They fail to show any of the true coronal structure, and the intensity of the halo around the solar image falls off gradually and uniformly as the distance from the limb increases. On account of the brightness of the sky it was necessary to give an exposure much too short for the comparatively feeble light of the corona. It is true that the speculum had been considerably tarnished by the fumes of the volcano, and with a perfect mirror the photographs would have been better. But a careful study of the experiments and results has led to the conclusion that even with perfect apparatus it would have been practically impossible to photograph the corona by the method employed, without much superior and possibly unattainable atmospheric conditions.

It would thus seem that the K band offers insufficient protection against the brilliant light of the sky. The photographic plate is unable, even when exposed only to this com-

paratively dark band, to distinguish between the light of the sky and that of the corona and sky together. During an eclipse the corona is photographed with the greatest ease, but when the bright light of the sky and the feeble coronal image meet the plate simultaneously the photographic method breaks down. On account of the inability of the eye or the sensitive plate to detect very small differences in the brightness of various parts of an illuminated object, the methods proposed for observing or photographing the corona in sunlight have almost without exception been based upon some plan of increasing the contrast between the corona plus sky and the sky alone.

At the meeting of the American Association for the Advancement of Science, at Brooklyn, in August last, I proposed two new methods of mapping the corona without an eclipse. It is the object of the present paper to describe the more important one of these methods.

When a bolometer is used with a reflecting galvanometer, it is well known that the galvanometer deflection is always proportional to the intensity of the radiation to which the bolometer is exposed. A moment's consideration will show the importance of this fact in the present connection. Let us suppose that an image of the Sun and its surroundings has been formed by a reflecting telescope, and that we wish to determine the radiation from the region lying outside the Sun's limb with a bolometer. Call S_D the deflection obtained when the bolometer is exposed to the sky at a distance D from the limb (D being greater than the radius of the corona); C_R, the deflection that would be given by the corona alone with the bolometer at the distance R from the limb; S_R, the deflection that would be given by the sky alone at this point. Then if a differential bolometer is used, with one member at the distance D, and the other at the distance R, from the limb, the deflection will be

$$G = C_R + (S_R - S_D).$$

Thus the absolute intensity of the sky radiation is of little importance; the value of $(S_R - S_D)$ measures the disturbing effect. During a total eclipse S_R differs little from S_D, and the radiation

measured would be in large part due to the corona. It is evident that D should be made as small as possible. When good conditions prevail at great altitudes above the earth, the brightness of the sky does not increase very rapidly as the Sun's limb is approached. In this case $(S_R - S_D)$ would be small, and the conditions of a total eclipse would be approximated. In any case the conditions are the same as though the sky were black up to a distance D from the Sun's limb. It can therefore hardly be doubted that the bolometer or radio-micrometer could be employed so as to indicate the coronal radiation, and to distinguish it from that of the Earth's atmosphere.

That this opinion is well-founded will appear from a closer examination of the question. Unfortunately our knowledge of the heat radiation of the corona is very slight, but two independent ways of treating the matter lead to results of the same order of magnitude, which will suffice for the present purpose.

In the first place let us consider the intensity of the corona's light, as determined by photometric measures made during total solar eclipses. Prior to 1878 the brightness of the corona was in most cases estimated by the observer, and it is not surprising that the conclusions differ widely among themselves. An examination of the observations made during total solar eclipses so carefully compiled and discussed by the late Mr. Ranyard[1] shows that few of the earlier estimates can be considered trustworthy. In 1860 Mr. J. M. Wilson was able to see the prominences and the lower part of the corona through the base of a wedge of dark glass, which extinguished the light of the full Moon at about its middle part.[2] At the eclipse of July 29, 1878, Professor J. W. Langley made some measures of the corona's light at his station on Pike's Peak. At a distance of 1′ from the Moon's limb the brightness was found to be six times that of the surface of the full Moon, while at a distance of 3′ the brightness was only one-sixtieth of that previously measured.[3] These observations, and

[1] *Mem. R. A. S.* **41**.

[2] *Loc. cit.* p. 251.

[3] *Wash. Obs.* 1876, Appendix 3, p. 214.

others on the total light of the corona made during the same eclipse, were discussed by Professor William Harkness. His conclusions were as follows:

"1. The total light of the corona was 0.072 of that of a standard candle at one foot distance, or 3.8 times that of the full Moon, or 0.0000069 of that of the Sun.

"2. The photographs show that the coronal light varied inversely as the square of the distance from the Sun's limb.

"3. The brightness of any part of the corona is given, quite approximately, in terms of the brightness of the surface of the full Moon, by the expression—

$$B = \frac{0.15}{h^2}(23' + 100' \cos \phi)$$

(where h is the distance from the Sun's limb in minutes of arc, and ϕ the latitude, measured from the Sun's equator, of the part in question). For very small values of h this formula fails. Probably the brightest part of the corona was about fifteen times brighter than the surface of the full Moon, or 37000 times fainter than the surface of the Sun.

"4. The corona of December 22, 1870, seems to have been seven and one-fourth times brighter than that of July 29, 1878."

The last conclusion was reached by a comparison of the 1878 measures with the results of some photometric observations made at Jerez, Spain, in 1870, by Mr. W. O. Ross, under the direction of Professor E. C. Pickering.

Professor Harkness is careful to point out "that, in deducing these results, visual and photographic data have been intermingled as if they were homogeneous. Such a procedure is certainly open to objection, but it is not likely that it introduced any error grave enough to impair the value of the results as first approximations.[1]

Subsequent investigations on the brightness of the corona have not borne out Professor Harkness' conclusions. Captain Abney's discussion of the results obtained at the eclipse of 1886

[1] *Wash. Obs.* 1876, Appendix 3, p. 392.

is adverse to the law of inverse squares;[1] and Professor W. H. Pickering's photographic photometry at the same eclipse showed the falling off in intensity to be much less rapid than Professor Harkness' formula requires.[2] Nor do the measures made on the negatives obtained by the Lick Observatory parties at the eclipses of January and December, 1889, decrease with such rapidity in going outward from the Sun's limb. The following table[3] brings together some of these results for comparison:

	Pickering, August, 1886	Holden, January, 1889	Holden, December, 1889
Intrinsic actinic brilliancy of the brightest parts of the corona	0.031	0.079	0.029
Intrinsic actinic brilliancy of the polar rays (about)	.....	0.053	0.016
Intrinsic actinic brilliancy of the sky near corona	0.0007	0.0050	0.0009
Ratio of intrinsic brilliancy of the brightest parts of the corona to that of the sky (actinic)	44 to 1	16 to 1	32 to 1
Intrinsic actinic brilliancy of the sky at 1° from the Sun in daylight (average)	40	....	....
Ratio of intrinsic brilliancy of the brightest parts of the corona to that of sky at 1° from the Sun in daylight (about)	1 to 1290	1 to 506	1 to 1379
Intrinsic actinic brilliancy of the full Moon	1.66	....	....
Ratio of intrinsic brilliancy of the brightest parts of the corona to that of full Moon.	1 to 53.6	1 to 21	1 to 57.2

The differences between the values obtained for the brightness of the corona at these eclipses are very striking. Professor Harkness considered the brightness of the brightest parts of the corona to be about fifteen times that of the full Moon, while the results obtained in 1886, and in January and December, 1889, were $\frac{1}{804}$, $\frac{1}{315}$ and $\frac{1}{858}$ respectively, if the brightness obtained

[1] *Phil. Trans.* (A.) 1889, p. 380.

[2] *Harvard Annals*, **18**, 100.

[3] E. S. HOLDEN: *Lick Observatory Report on the Observations of the Total Eclipse of the Sun, December 21–22, 1889*, p. 14.

by Professor Harkness be taken as unity. Moreover, Professor Harkness concluded that the corona of 1870 was 7¼ times brighter than that of 1878.

A number of causes might conspire to produce these remarkable differences. The duration of totality, altitude of the Sun and consequent variation in atmospheric absorption, clouds or haze during totality, and differences in the methods employed are all to be considered, in addition to changes in the corona itself.

1878 was a year of minimum Sun-spots, and at the time of the eclipse spots and prominences were few and small. The photometric measures of Professor Langley were made on Pike's Peak (14,147 feet) on July 29, when the Sun's altitude was over 40°. The duration of totality was about $2\frac{1}{2}^{m}$. During the entire eclipse the sky was perfectly clear, and of a deep blue color. The eclipse of August 29, 1886, occurred during a Sun-spot maximum. Professor Pickering's photographs were made at sea-level in the exceedingly moist atmosphere of the island of Grenada. The duration of totality was about $6\frac{1}{2}^{m}$, so that the lowest and brightest parts of the corona were covered most of the time. The observations were made through passing clouds, and after 156 seconds of totality the corona was covered with hazy clouds, which rapidly grew denser, so that nothing could be seen 24 seconds later. The Sun was only 20° above the horizon during the eclipse. Most of the photographic plates were ruined by the moist atmosphere, and the photometric measures made on those that were preserved are surely subject to some uncertainty.

The two eclipses of 1889 came in a period of minimum solar activity. On January 1 there were clouds before and after the eclipse, and during totality the corona was seen through a slight haze. The altitude of the Sun was 24° 6′, and the duration of totality about 2^{m}. The station of the Lick Observatory party was 2040 feet above the level of the sea.

In December the conditions under which the Lick party observed were somewhat similar to those experienced by Professor W. H. Pickering in 1886. The station at Cayenne was

little above the level of the sea, and the climate was very damp. The altitude of the Sun was about the same as in the eclipse of January. Just before second contact a heavy rain fell, and during totality the conditions were not at all favorable. The plates were developed soon after the eclipse, and it was found that the extreme moisture had not affected them appreciably. They were all greatly over-exposed.

The Carcel burner used to standardize the plates from which the photometric results in the table for the eclipses of 1889 were deduced, was found to be constant for an hour or more, but "enormous variations occur between the results of different days (so that no results can be drawn from a comparison of plates standardized at different times)."[1] Professor Holden expressly states that until the reductions can be repeated the results are to be regarded as provisional.

It would appear from a comparison of these results that the determinations of the brightness of the corona made by Professors Pickering and Holden are in some respects less satisfactory than the values given by Professor Harkness, though it is not probable that the brightness falls off so rapidly as the law of inverse squares requires. Professor J. W. Langley's observations seem to me quite sufficient to prove that the *visual* brightness of the corona and sky at a distance of 1′.66 from the Sun's limb was at least as great as that of the surface of the full Moon. This differs so widely from the photographic results that one is led to suspect the existence of a maximum of intensity in the lower part of the coronal spectrum. In spite of the meagerness of the data at our disposal it is possible to derive conclusions of some value in this connection.

The few observations made prior to the eclipse of 1878 seemed to show that the polarization of the light of the corona increased toward a maximum in passing outward from the Moon's limb.[2] In an important theoretical discussion, published in

[1] A. O. LEUSCHNER: *Lick Observatory Report on the Total Eclipse of December 21–22, 1889*, p. 9.

[2] RANYARD: *Mem. R. A. S.* **41**, 260.

1879,[1] Professor Arthur Schuster assumed various laws of distribution of the polarizing particles in the corona, and applied his conclusions to the observations of Winter at the eclipse of 1871. Mr. Winter found the polarization to be greater at a point about 10′ from the Moon's limb than at another point closer to the limb.[2] The proportion of polarized light to the whole light in the former position he determined to be about 0.246. Professor Schuster, while not attaching great importance to these results, assumed the maximum of polarization to be at just the point observed by Mr. Winter, and calculated the amount of light due to scattering matter uniformly distributed in the corona to be over 90 per cent. of the whole. This assumption of uniform distribution he pointed out to be very improbable, as, if it were true, the light not due to scattering particles would increase at an extremely rapid rate in going out from the limb. If, on the other hand, the density of the scattering matter varied inversely as the square of the distance from the Sun's center, only about one-half of the light would be due to it. With this law of distribution the light not due to scattering would decrease outward from the limb. Professor Schuster concluded that at the eclipse of 1871 the intensity of the scattered light was probably little more than one-half of that of the total light.[3]

At the eclipse of July 29, 1878, Professor Arthur W. Wright made a very thorough visual and photographic investigation of the polarization of the coronal light. None of the photographs gave any trustworthy evidence of a region of maximum polarization at a distance from the limb. On the contrary, many of the plates showed a distinct increase in the intensity of polarization near the limb. With the polarimeter the value of the polarization between 4′ and 10′ from the Moon's limb was found to be nearly 12 per cent.; between 12′ and 18′ it was 4.7 per cent.; at 22′ there were traces of polarization, but the light was too feeble to permit of measurement. The polarization was nearly

[1] *M. N.* **40**, 35.

[2] *Mem. R. A. S.* **41**, 324.

[3] *M. N.* **40**, 54.

uniform around the circumference, except in regions extending 20° on each side of the poles, where it was somewhat greater. The observations did not seem to be affected by the passage of polarized rays through the Earth's atmosphere.

In his concluding remarks Professor Wright offers an explanation of the results. From the fact that the polarization is radial, it is clearly due to reflection of solar light from matter in the corona. Finely divided matter, such as that of vapors just in the act of condensing, polarizes light completely at an incidence of 45°. On account of the intense heat of the Sun, matter in this form would very likely be found near the surface, while farther out in the corona larger particles would be more numerous. For these particles the polarization would increase outward from the Sun. But as they approached the photosphere they would be greatly reduced in size, or even vaporized; and in this condition their polarization would probably be sufficient to produce the effect observed. "The inner portions of the corona must be of sufficiently high temperature to be self-luminous, a circumstance which would diminish the apparent percentage of polarization, and in part explain the smallness of its amount. As the light thus emitted must come chiefly from matter in the solid form, its spectrum would be continuous, in the absence of any atmosphere sufficient to produce dark absorption lines. Moreover, as this light is superadded to that which is reflected, it would diminish the intensity of the dark lines of the spectrum, caused by the latter, and render them more difficult of observation—a fact in harmony with experience."[1]

The conclusion thus deduced from polariscopic observations of the existence of incandescent particles in the coronal atmosphere is strengthened by a consideration of the temperature conditions which must exist in the corona. Mr. Ranyard pointed out in 1891[2] that experiments with great "burning glasses" are sufficient to show that the temperature in the coronal region must be high. Platinum would certainly melt at distances

[1] ARTHUR W. WRIGHT: *Wash. Obs.* 1876, Appendix 3, p. 280.

[2] *Knowl.* **14**, 14.

but little less than a solar radius. Many of the glowing particles in the lower regions of the corona are thus in all probability liquid; but the most refractory substances may also be present in the solid state.

It is evident that the scattering effect of the smallest particles in the corona must be most marked for light of short wavelength. If most of the particles within a certain radius are small in comparison with a wave of blue or violet light, the scattered light, could it be observed alone, would probably exhibit a maximum at the upper end of the spectrum. But we have just seen that the scattered light is only a part of the total radiation of the corona. The maximum of intensity in the continuous spectrum of the glowing particles must be displaced toward the red as compared with the spectrum of the photosphere, as the particles are at much lower temperature. The absorption in the upper part of the solar spectrum tends to produce a similar shift of the maximum; and the spectrum of the scattered light must be added to that of the luminous particles to give the true coronal spectrum. Hence, in spite of the lower temperature of the corona and the fact that the coronal radiation is not subject to the general absorption, the maximum may not be much lower than that of the spectrum of the photosphere.[1]

We may safely conclude that the coronal spectrum is of considerable intensity in the yellow, red, and infra-red, and that its heat radiation should be easily measurable. It is strange that but few attempts have been made to measure this radiation during total eclipses. In 1842 Magrini found that the heat of an image of the corona formed by a reflecting telescope was such as to move the index of a Rumford thermoscope half through the scale by the end of totality, while the heat from the full Moon could not be detected with the same apparatus. Unfortunately, Magrini's description of his work does not give all of

[1] For various reasons the observations that have been made on the relative intensity of different parts of the coronal spectrum can hardly be depended upon to decide this question. The photographs are quite as unreliable, as plates equally sensitive to all parts of the spectrum have never been employed.

the details, and it is impossible to assign a proper weight to the result.[1] In 1860 Sir William Thomson (now Lord Kelvin) proposed that the heat of the corona be measured by spirits of wine or mercury thermometers of the ordinary form, and pointed out that a mirror would be better than a lens for this work "because the hot dust around the Sun must produce radiant heat of such colour as that of a hot stone or metal not at a bright red heat."[2] This suggestion does not seem to have been acted upon, but in 1878 Mr. T. A. Edison exposed his recently invented "tasimeter" to the total light of the corona, and the galvanometer needle was thrown off the scale.[3] During the same eclipse Professor Young placed a thermopile in the infra-red region of the coronal spectrum, and obtained a doubtful indication of a heat band.[4]

So far as I am aware the observations of Magrini and Edison are the only ones hitherto made on the heat radiation of the corona. Taken in connection with the results obtained for the brightness, they certainly seem to show that the bolometer ought to indicate a greater intrinsic radiation from the corona than from the full Moon.

In the following discussion of the sensitiveness of heat-measuring instruments the bolometer alone will be considered, as for it the required data are most readily obtainable. The experiments of Boys and Paschen seem to show that the radiomicrometer may also be advantageously employed, and the thermopile or selenium cell might be modified to meet the special requirements of the investigation. In all of my preliminary experiments I have used bolometers exclusively.

In his Prize Essay *On the Distribution of the Moon's Heat and its Variation with the Phase*[5] Professor Frank W. Very has given data which are valuable for our purpose. The bolometer

[1] RANYARD: *Mem. R. A. S.* **41**, 246.

[2] "On the importance of making Observations on Thermal Radiation during the coming Eclipse of the Sun." *M. N.* **20**, 317.

[3] *Am. J. Sci.* **117**, 52.

[4] *Princeton Review*, 1878, 884.

[5] Published by the Utrecht Society of Arts and Sciences, The Hague, 1891.

employed exposed a sensitive surface of about 19 square millimeters. The image of the Moon, about 28^{mm} in diameter, was formed by a silver-on-glass mirror, the aperture of which is not mentioned. With the galvanometer used, a small region near the center of the disk of the full Moon gave a deflection of nearly 100^{mm} scale divisions.

With similar apparatus we might expect to obtain at least this deflection for the brightest parts of the corona, if the bolometer were used differentially, and S_R were equal to S_D. As $S_R > S_D$ the deflection should be somewhat greater.

It is evident, however, that if we wish to map the corona, so as to show its structure, a much higher "resolving power" will be required. To secure this, the bolometer must be made much smaller, and its greatest dimension should be radial to the Sun. With a 28^{mm} solar image the bolometer strip might perhaps be 2^{mm} long (radially) and $0^{mm}.5$ wide. As much of the coronal structure is radial, or nearly so, such a bolometer would be small enough for a preliminary investigation. Its area would be only $\frac{1}{19}$ of that used by Professor Very, and with an equally sensitive galvanometer the deflection due to the corona alone might not exceed 5 or 6 divisions. Fortunately, however, a galvanometer about 75 times as sensitive as the Allegheny instrument may now be constructed, and its deflection with the small bolometer should be not less than 350 or 400 divisions. With good conditions of steadiness and freedom from magnetic disturbances, a deflection of $\frac{1}{8}$ division can be determined with certainty. A variation in the coronal radiation of one part in 1500 should therefore be measurable.[1] If such a bolometer were exposed to various parts of the image, the general structure of the corona

[1] The differential method to be employed will reduce the effect of variations in the radiation of the Earth's atmosphere to a minimum, as in most cases both bolometers will be affected alike. Irregularities in the curve not due to the corona can be eliminated by repeated experiments. The effect of increase in brightness of the sky toward the Sun's limb will he shown in a gradual change in the length of the mean ordinate of the curve. The resulting effect upon the appearance of the coronal image will be analogous to that produced by the brightness of the sky and diffraction at the Moon's limb during an eclipse. (See Barnard: *Lick Observatory Report on the Total Eclipse of January 1, 1889*, pp. 65, 69; Keeler: *Ibid.*, p. 45).

could be made out in a manner similar to that employed in 1868 to determine the form of prominences by means of visual observations of the $H\alpha$ line with a narrow slit.

Although results of some value could probably be obtained by this process, yet it is evident that a much better method is desirable for the purpose of making daily records of the form and structure of the corona. A means of accomplishing this would be to move the bolometer over the coronal image (or the image over the bolometer) in a manner similar to that employed by Professor Langley in his spectro-bolographic work. A photographic plate upon which the spot of light from the galvanometer mirror falls is moved synchronously with the bolometer (or image) at right angles to the direction of the deflection. A curve is thus photographed, whose ordinates measure the heat radiation to which the bolometer was exposed in the corresponding positions on the image. It is perhaps simplest to consider the bolometer to be moving in a circle just outside the Sun's limb. After it has completed one revolution, it is moved out radially a distance equal to its own length, and is then moved through another circle concentric with the Sun. The photographic registration is meanwhile continued with no interruption other than the momentary one due to the shifting of the bolometer. This process is repeated until the entire corona has been traversed by the moving bolometer; the other bolometer of the pair being maintained in a fixed position on the image of the sky at a distance of from 30′ to 100′ from the Sun's limb.[1] The result will be a nearly continuous photographed curve showing the heat radiation from all points in the corona.

Instead of being moved in a straight line the photographic plate may be rotated about its center. In fact, the bolometer may be on one side of a disk, and the sensitive plate on the other. This extremely simple arrangement would render complicated synchronizing apparatus unnecessary. A slight modification of the same plan would allow rectilinear motion of the plate. But if the plate were made to rotate, we would have a series of

[1] Preferably in the region of the pole.

closed curves of increasing radii, whose maxima and minima would enable us to determine at a glance the general form of the corona. The distortion of the curves could easily be removed if necessary.

It will be advantageous, however, to go a step further in order to obtain an image of the corona comparable with an eclipse photograph. Suppose a photographic plate to be placed behind a screen which is illuminated by parallel light from a constant source. In the screen is an opening equal in length to the bolometer strip and variable in width. The screen is mounted upon an axis opposite the center of the sensitive plate, and the radius of the circle described by the opening when the screen is rotated is made equal to the radius of the circle described by the bolometer in its motion over the coronal image at the focus of the telescope. The width of the slit in the screen is controlled by the galvanometer curve, which is cut out of pasteboard or other suitable material. It is evident that if the screen is rotated at a uniform speed before the plate and the curve moved at a corresponding rate over the controlling mechanism, the intensity of the photographic action at any point will be nearly proportional (or, by a slight change, inversely proportional, if a positive is required) to the ordinate of the curve at the corresponding point. After the first circle has been photographed, the sliding strip which carries the opening in the screen is moved out through a distance corresponding with the length of the bolometer strip, and the process is repeated with the second section of the curve. Continued repetition of this procedure will give a negative (or positive) of the corona.

Professor F. L. O. Wadsworth, to whom I am indebted for many valuable suggestions, has pointed out that the screen might be fixed at a distance, with a lens interposed to form an image of the uniformly illuminated opening (equal in size to the bolometer strip) upon the photographic plate. The lens is covered by a diaphragm which exposes only a narrow strip across the center. The opening in the screen is placed at a distance from the optical axis of the lens equal to the radius of

the circle described by the bolometer in its motion around the Sun. The photographic plate is made to revolve at a uniform speed about the optical axis of the lens, and the galvanometer curve, cut out of stiff material, is moved synchronously across the diaphragm in the lens, at right angles to it. The brightness of the spot of light upon the moving plate should thus be inversely proportional to the ordinate of the curve at the point where it crosses the diaphragm. Repetition of the process will gradually build up a positive image of the corona.

Many other methods of accomplishing this result will suggest themselves. A very simple one has recently occurred to me. In the first method described above we may replace the photographic plate by a sheet of white paper, and employ, instead of parallel light, one of the "air brushes" used by photographers in working up bromide enlargements. In this ingenious little device a stream of air, carrying with it finely divided India ink, is thrown upon the paper. The flow is regulated by pressure of the finger upon a delicate valve. For our purpose the air brush is supported over the opening in the screen (which is made equal in size to the bolometer strip), and the flow of ink is regulated by the galvanometer curve, which is cut out of stiff material, and moved over the valve.[1]

It may be urged that the methods suggested are too slow to be of practical value, especially as the bolometer should move over its own width in the time of swing of the galvanometer (for this work about ten seconds). To obviate this, several bolometer strips may be mounted end to end, so as to form a compound bolometer extending out from the Sun's limb to a distance of from 20′ to 30′. All the bolometers would be differential, as before, the second member being placed outside the corona. As many galvanometers as there are bolometers would be required. In transforming the curves into an image

[1] The bolometer might also be moved over the corona in a spiral path or in straight lines; the transformation methods may be easily modified to conform to these conditions.

A little consideration will show that the galvanometer might be made to record an image of the corona directly upon a photographic plate, if this were thought desirable.

of the corona any of the processes suggested may be used, with one or several openings in the exposing screen.

The time required for the operation might be still further decreased by using another form of compound bolometer, consisting of a large number of short radial strips mounted in two parallel planes, separated by a thin air space. The members could thus be made to overlap slightly, so that the entire corona would be covered with bolometers. All of these bolometers would be used differentially with one or several galvanometers. The battery current would flow through them constantly, and the galvanometer circuits would be completed by a system of rotating contacts. As each bolometer would be constantly exposed to the coronal radiation, the difficulties due to exposure of a single strip to rapidly varying heat conditions would in part be obviated, with a consequent gain in the rapidity of the process. The chief objection to the compound bolometer in either form is the impossibility of making all the strips of exactly the same size and resistance. Professor Wadsworth has, however, suggested methods by which this difficulty may be in large part overcome.

In my experiments at the Kenwood Observatory I have carried the preliminary investigations as far as the conditions will allow; they have dealt chiefly with the construction and testing of various forms of phosphor-bronze, platinum and steel bolometers.[1] The location of the Observatory is quite unsuitable for work with the delicate apparatus required. The galvanometer, which is being constructed under Professor Wadsworth's supervision, promises to be even more sensitive than the extremely delicate instruments designed by him for the spectro-bolographic work of the Smithsonian Astrophysical Observatory.[2] Such a

[1] The bolometers were mounted in a brass tube, provided with a large number of diaphragms, each of which was blackened on the lower and polished on the upper surface. This tube was soldered within another brass tube of much larger diameter, with double walls at the end. Water was constantly passed through the chambers at the end and sides; the bolometers were thus screened from the radiation of the room, and completely protected from the intense heat of the direct solar image. Only the heat of the corona and sky could reach them through the small openings of the diaphragms.

[2] See the February number of this JOURNAL, p. 163.

galvanometer cannot be used in the midst of a large city. The smoke is another obstacle, as it increases the atmospheric absorption, and also the value of $(S_K - S_D)$. The special apparatus for the investigation will probably be completed by the end of May, when it is expected that the instruments of the Kenwood Observatory will be transferred to the new Yerkes Observatory at Lake Geneva, Wisconsin. There the conditions for continuing the work on the corona could hardly be surpassed, especially at the time of the summer solstice.

It is evident that the method described in this paper may be applied to many purposes other than that for which it was primarily designed. The bolometer, radio-micrometer or thermopile will be used, as circumstances may require, in a number of investigations to be undertaken soon by myself and my assistants. The heat-measuring apparatus will be used alone, or in connection with a spectroheliograph, in attempts to obtain "heat images" of the corona, prominences, spots, faculæ and other solar phenomena, and also of the Moon. Other investigations depending upon this method, or closely allied to it, will be described in a future paper.

KENWOOD OBSERVATORY, CHICAGO,
March 15, 1895.

ON A NEW FORM OF SPECTROSCOPE.[1]

By C. PULFRICH.

IN the construction of the spectroscope which is described below, an attempt has been made, and I believe for the first time in this form, to apply the method of normally reflected rays, or principle of reversed path, to the well-known compound prisms of Rutherfurd (a flint-glass prism of large angle cemented between thin prisms of crown glass) and of Wernicke (ethyl cinnamate instead of the flint glass). In doing this I believe that I have obviated certain difficulties attending the use of these prisms (which are so favorably known on account of their high dispersion and transparency) in previous constructions, and have made them more suitable for spectroscopic and perhaps also for spectrographic[2] studies than they were before.

The advantages of the method of normally reflected rays, as applied to the spectroscope, lie chiefly in the two following points — to which may be added the less important one of convenience in observation, inasmuch as the different parts of the spectrum are observed without changing the position of the telescope or photographic plate: *first*, the position of minimum deviation is given to the system of prisms by a comparatively simple arrangement, so that any spectral line in the center of the field of view is necessarily seen under the conditions of maximum distinctness, and *second*, the focal length of the collimator and observing telescope can be made relatively very great without making the apparatus inconveniently large for practical use; other circumstances being equal, a considerable increase in purity and extension of the spectrum is in this way obtained.[3]

Let us first consider somewhat more closely the forms of

[1] Translated from the *Zeitschrift für Instrumentenkunde*, 10 Heft, 1894. Communication from the optical establishment of Carl Zeiss, in Jena.

[2] Compare Lohse, *Z. f. Instrum.* 1885, p. 11.

[3] Compare Lippich, *Central-Zeitung für Optik und Mech.*, 1881, pp. 49 and 61.

spectroscope to which the principle of reversed path has already been applied.

The first application of the principle to the construction of a spectroscope with only a single prism seems to be due to Duboscq, who followed the designs of v. Littrow.[1] In front of the telescope, which was fixed, and provided with some form of slit, (how the slit was arranged I have not been able to ascertain) was a 30° prism, capable of rotation about an axis *M* (Fig. 1).[2]

The back surface of the prism was silvered. Duboscq recognized the features which are characteristic of his method, namely: that the length of path of a ray returning upon itself is exactly the same as if it passed through a prism of twice the angle

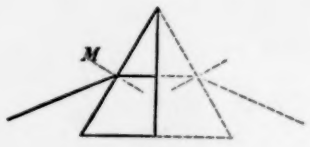

FIG. 1

(or 60°) in the position of minimum deviation; further, that a simple rotation of the prism sufficed to bring the different colors into the field; and finally that, other circumstances being equal, the dispersion is exactly the same as in the case of an entire prism. It is, therefore, somewhat surprising that this Duboscq spectroscope should be almost unused in laboratories, while the ordinary form of spectroscope with 60° prism is so common.

The first application of the same principle to several prisms of 60° each, placed so as to form a train, is due to v. Littrow. The (four) prisms could be so moved, by means of a special mechanical device, that each prism remained in the position of minimum deviation for the normally reflected and observed ray. The path of a ray is shown in Fig. 2 sufficiently well for the pur-

[1] v. Littrow, *Wien. Ber.* **47**, II, 29, 1863.

[2] In principle, therefore, exactly the same arrangement as in the spectrometer by Professor Abbe, which is so admirably adapted to measurements of the refractive and dispersive powers of a body. (*Z. f. Instrum.* 1889, p. 361, and *Katalog über optische Messinstrumente von Carl Zeiss*, Jena, 1893.)

pose of illustration. The resulting dispersion is in this case also equal to that of twice the number of prisms when the ray is transmitted. Littrow also mentions the plan, later repeatedly carried into execution,[1] of increasing the dispersion fourfold by means of a special reflecting prism, which transferred the rays to another story before they were finally sent back on the same path.

Following v. Littrow, the principle of reversed path was used in the construction of spectroscopes by many persons (Browning,

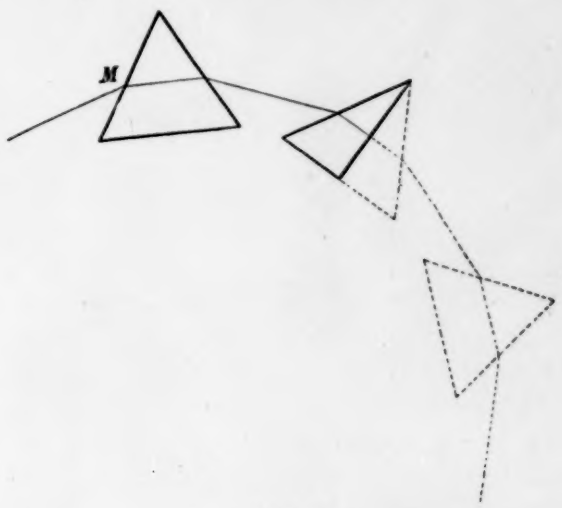

FIG. 2

Hilger, Krüss, Grubb, Brackett and others).[2] The device for keeping the prisms in the position of minimum deviation has been gradually perfected in these different forms of apparatus.[3] In another respect also these now very popular forms of spectroscope have been brought to a continually increasing state of perfection; the arrangement by which the reflecting half-prism (or mirror) can be introduced between any two prisms of the train is

[1] Compare, among others, Cornu, *Z. f. Instrum.* 1883, p. 171.

[2] Compare Krüss, "Ueber Spektralapparate mit automatischer Einstellung," *Z. f. Instrum.* 1885, pp. 181 and 232; 1888, p. 388.

[3] See in particular the ingenious arrangement recently described by Krüss. (*Z. f. Instrum.* 1890, p. 97.)

especially worthy of mention. It enables the observer to alter at will the dispersion of his apparatus, within certain limits determined by the number of prisms in the train, without in any other way changing the disposition of the parts of the instrument.[1]

With regard to the application of the principle of reversed path to the compound prisms of Rutherfurd or Wernicke, we have here two different ways, one of which has already been taken by Krüss,[2] Prazmowski,[3] and Schmidt and Haensch,[4] and which consists in either wholly or partly replacing the 60° prisms of the automatic apparatus already described by compound prisms. As compared with 60° prism spectroscopes of equal dispersion these spectroscopes have at least the advantage of giving brighter spectra, on account of the smaller number of internal reflections.

The second, and as it seems to me the more direct way, is that which I have taken in constructing the spectroscope described in this paper. It will be seen from the following description that the construction is closely analogous to that of Duboscq.

We may regard every Rutherfurd or Wernicke prism, whether it consists of three or of more than three component prisms, as divided by a plane passing through the refracting edge of the central prism, into two parts, which are symmetrical with respect

[1] A new form of Littrow spectroscope, differing somewhat from the above, is described by Mr. F. L. O. Wadsworth in the July (1894) number of the *Philosophical Magazine*. The special feature of this apparatus is that the objective is replaced by a silvered concave mirror of about 1.7 meters (or another of 4.7 meters) focal length, with the object of entirely avoiding the annoying reflections produced by the surfaces of an objective. The rays coming from the slit are thrown by a small totally reflecting prism upon the concave mirror, which reflects them as a parallel bundle to a 60° prism of flint glass, behind which is a plane mirror. The same concave mirror unites the returning rays to form an image of the spectrum. This ingenious apparatus would probably be considerably improved if the prism and plane mirror were replaced by the combination which is described further below in the present article. I have been informed by a personal communication that Messrs. Kayser and Runge have constructed an apparatus quite similar to that of Wadsworth, with which they intend to photograph spectra *in vacuo*.

[2] Krüss, *Z. f. Instrum.* 1887, p. 183.

[3] Prazmowski, *Z. f. Instrum.* 1889, p. 106.

[4] Schmidt and Haensch, *Spezial-Katalog, Ausstellung in Chicago*, 1893, p. 70.

to the plane (Figs. 3 and 4). Each half, when the rays are returned on their path by reflection, is equal in dispersive power to the original prism with transmitted rays. It is also evident that the automatic adjustment for minimum deviation is obtained by rotating the prism about the axis M, exactly as in the case of the simple prism illustrated in Fig. 1.

This arrangement also enables us to make the spectroscope equal in dispersive power to any number of 60° prisms, without obliging us to use any other device for automatic adjustment than the simple axis of rotation. This axis not only answers the required purpose in the most perfect manner, but it has a still further advantage; the apparatus for measuring the distances between spectral lines (graduated circle and micrometer micro-

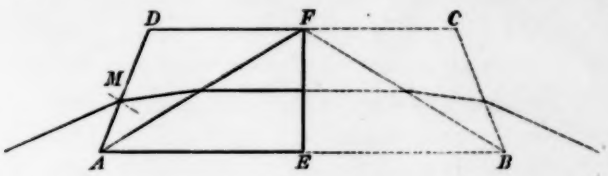

FIG. 3

scopes) can be attached directly to the most rigid part of the instrument,—the axis of rotation,—in consequence of which a much higher degree of accuracy can be reached in the measurements than with other methods of construction.

It will be readily understood that practical reasons prevent us from indefinitely increasing the dispersive power of a compound prism by increasing the number of component prisms. The technical difficulties of construction in doing this grow at a greatly increased rate. A certain limit is thus set to the increase of dispersion, which can be exceeded only at the cost of the purity of the spectrum. Viewed in this light, the construction which we are considering is very favorable, inasmuch as we have to do with only half of the prism. We require therefore only half of the material, half the number of cemented surfaces, and what is also of importance in the technical production, we do not require the prism angles on opposite sides of the plane of

symmetry to be rigidly equal, as they must be in the ordinary construction. This condition is necessarily fulfilled with absolute exactness.

It is at least certain that the production of compound prisms consisting of only two or three single prisms does not present any difficulty worth considering. We shall illustrate the action of such prisms, made up of two or three parts, by means of a few examples.

The prism represented in Fig. 3 consists of a prism of flint glass combined with one of crown glass (both Jena glass of relatively very great transparency), in which the highest degree of dispersion that can be obtained with a double prism is purposely avoided, and in fact is not nearly approached.[1] The combination is remarkable for the brightness of the spectrum in the violet. The optical constants of the glass (refraction and dispersion) expressed in the usual manner, are as follows:

Flint glass prism *AEF*, refracting angle $= 57°$
$n_D = 1.6800$, $n_F - n_C = 0.02152$, $\nu = 31.6$;
Crown glass prism *AFD*, refracting angle $= 40°$
$n_D = 1.5170$, $n_F - n_C = 0.00847$, $\nu = 61.0$.

From these data the dispersion, *i. e.*, twice the difference of direction of the rays normally reflected on the back surface (twice the angle of rotation of the prism) is by computation $4° 34'$ between C and F. Taking the dispersion of a single $60°$ prism of ordinary flint glass ($n_D = 1.62$) for the same lines, as $1\frac{1}{2}°$, the combination represented in Fig. 3 is equal in dispersion to three such prisms.

A correspondingly greater dispersion can be obtained by using three prisms cemented together. It will in that case be equal to the dispersion of a Rutherfurd prism with five members, and can be made equal to the dispersion of six, seven or eight single prisms of $60°$, according to the optical constants of the glass used in the construction of the prism.

We see therefore that it is not difficult, by using only two or

[1] The spectroscope furnished with this prism (see further below) shows the nickel line between the two solar D lines very distinctly.

three component prisms, to find a combination which is practically easy to make, and which is capable of satisfying comparatively high requirements with regard to dispersion.

It will perhaps still be of interest to see how our construction is applied to the fluid ethyl cinnamate, which was preferred by Wernicke to the strongly absorptive flint glass. I believe that the simplest and most advantageous arrangement is that shown in Fig. 4, which represents a combination with three members, and is one which I have practically carried out. With careful regulation of temperature it gives very good images.

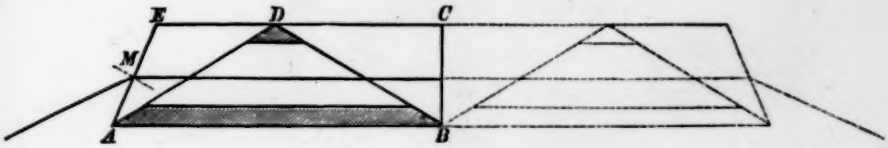

FIG. 4

ABD is a glass tube, the ends of which are cut off obliquely and cemented to the crown glass prisms *ADE* and *BCD*. The refracting angle of the resulting hollow prism is 120°, that of the glass prisms 35° and 63° respectively. A good quality of the fluid was obtained from C. F. Kahlbaum in Berlin.

The optical constants are as follows:

Ethyl cinnamate	$n_D = 1.5607$,	$n_F - n_C = 0.0286$, $\nu = 19.6$,
Crown-glass	$n_D = 1.5170$,	$n_F - n_C = 0.0085$, $\nu = 61.0$,

from which we find that the dispersion from C to F is 12°.1, or about the same as that of eight flint glass prisms of 60°.

It will perhaps be noticed that in both Fig. 3 and Fig. 4 the incident ray strikes the first surface of the prism at the same angle of about 45°. The reason is that I wished a comparison scale reflected from the surface of the prism to be seen in the field of view alongside of the spectrum, and took this fact into account in computing the combination. The most favorable conditions are obtained when the tube containing the scale is nearly at right angles to the observing telescope. In cases where the comparison scale is not required, it is well to compute

the combination so that the angle of incidence on the first surface is less than 45°, as the loss by reflection will then be diminished.

From what has been said above it is evident that the other parts of the spectroscope can be constructed without regard to the particular form of prism employed. This circumstance makes it possible to exchange any given prism for another one of greater or less dispersion, without altering any other part of the entire apparatus. It is easy to so arrange the prism-holder that the prism can be removed by a suitable handle and replaced by another, which may be, for example, an ordinary 30° prism of flint glass, and the observer is thus enabled to work quickly and conveniently, sometimes with higher and sometimes with lower dispersion, according to the requirements of the special case in hand. An instrument provided with three prisms, one of the ordinary 30° form, one compound with two members, and another compound with three members, would probably answer even somewhat exacting requirements.

We will now undertake to illustrate a little more completely the special application of the above principles to the construction of a spectroscope. Fig. 5 is a side view of the instrument; Fig. 6 shows the course of the rays, and Fig. 7 the arrangement of the slit and eyepiece.

What first strikes the eye in looking at Fig. 5 is the circumstance that the instrument is mounted so that it stands obliquely. For laboratory practice it is possible that this position may be more convenient than the customary horizontal one; at least it has been found so in the experiments which have been made up to the present time. This is, however, merely a matter of taste, in which, of course, no fixed standard can be referred to.

A short description will indicate clearly the relation of the different parts. P is the compound prism, fastened to a plate which can be rotated about an axis A. The prism is rotated through any considerable angle by hand, the angle being read on the arc T, which is graduated to half degrees by means of an index. The slow motion is effected by means of the micrometer

screw *M*, after the clamp *K* has been tightened. With this arrangement the angle can be read to one division of the micrometer head, or 10″. The parts just described are in a position where they are easily reached by the right hand of the observer, whose arm rests on the table. The micrometer head and graduated arc are also read without difficulty. On the left side of

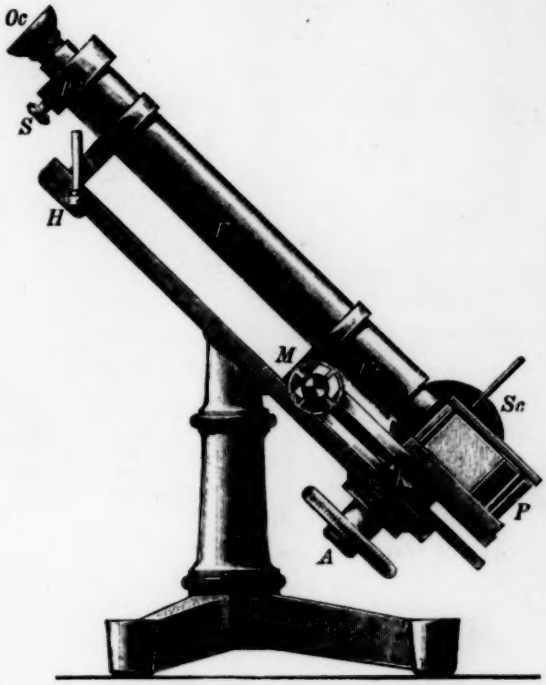

FIG. 5 (¼ actual size)

the observer, opposite to the prism, and perpendicular to the telescope, is fixed the tube which contains the scale and its collimator O_1. The scale is divided on lamp-black from λ 750 to λ 400 in units of the second decimal place. By means of a small screw *E*, the tube can be rotated about an axis parallel to that of the prism, so that the observer can always adjust the scale to read correctly. Between the prism and O_1 is a movable screen which shuts off the light from the scale when necessary, and intercepts

the reflected images of the slit produced by the two surfaces of the objective O_1.

A particular interest naturally attaches to the arrangement of the observing telescope F, which at the same time fulfils the function of a collimator. The objective Ob has an aperture of 21^{mm} and a focal length of 255^{mm}, and the two eyepieces belong-

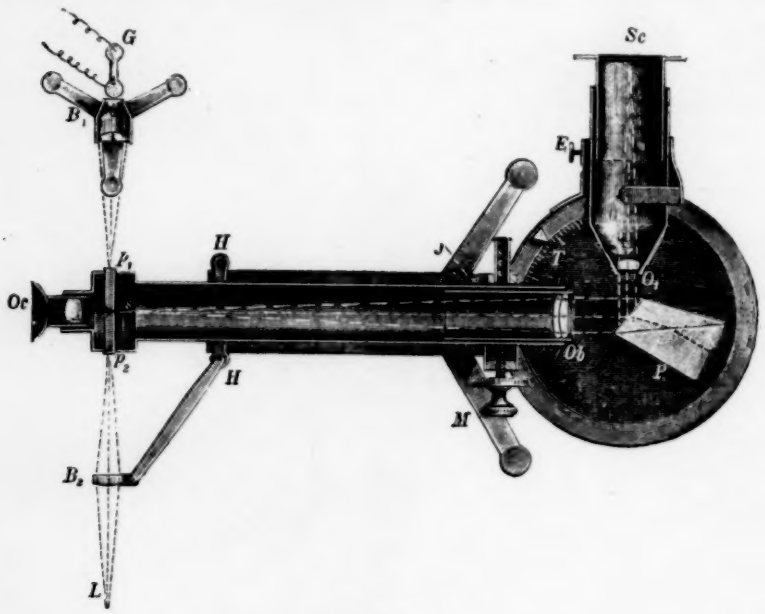

FIG. 6

ing to the instrument magnify 6 and 12 times respectively. In the focal plane of the objective is placed the slit apparatus shown in Fig. 7. The slit can be set to any required width by means of the graduated head S, and there is no danger of injuring the jaws by turning the screw too far. The slit is so arranged that the lower half of the field of view is left entirely free for observation. p_1 and p_2 are two reflecting prisms, placed alongside of each other over the slit plate, which allow the spectra of two sources of light, one on the right and one on the left, to be simultaneously seen and compared by the observer. The two

spectra S_1 and S_2 are observed in the lower half of the field with the eyepiece. All false light coming from the prisms p_1 and p_2 is prevented from reaching the eye by a plate which covers the upper half of the field of view. The mark used in setting, which is not shown in Fig. 7, is a double cross ruled on glass, and must be so placed that the two points of intersection are in the line of the slit produced, and each separately is nearly in the middle of its corresponding spectrum.

The method for exactly focusing the slit is the same that I used in constructing the Abbe-Fizeau dilatometer,[1] and it is one to

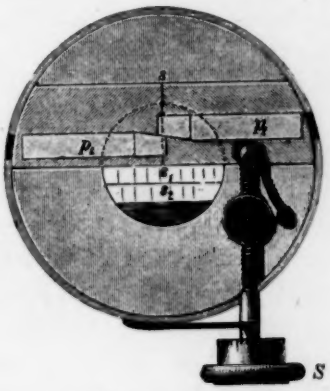

FIG. 7 (actual size)

be recommended for any telescope when the principle of reversed path is applied. It consists merely in focusing the objective instead of the slit. A small pin *J*, projecting through the telescope tube, serves as a handle for moving the slide. The great advantage of this arrangement is that the sources of light reflected by $p_1 p_2$ need be only once adjusted, and do not afterwards require any change. The axial displacement of the objective has no effect on this adjustment.

For the study of different sources of light a number of accessories are provided, which are generally held by the arms *H* when the instrument is in use. They are: a pair of plane mirrors

[1] *Z. f. Instrum.* 1893, p. 376.

movable in any direction, a pair of ordinary convex image lenses, holder for test-tubes, support for absorption cells (the last two placed close to the small apertures in front of the reflecting prisms), and finally a special mounting for "end-on" Geissler tubes. The two lenses, one of which is shown at B_2 in Fig. 6, and the apparatus B, in the same figure, serve to converge the rays from the luminous source upon the slit. The apertures and distances of the lenses in the system are so chosen that the objective is filled with light. The observer can easily assure himself that the source of light is properly adjusted, by first testing with a piece of paper the course of the rays where they enter the small apertures, and then removing the eyepiece, by looking in directly at the objective. It will be seen at once what part of the objective is covered by the rays and whether any further adjustment of the source is necessary.

In working with sunlight, which is thrown upon the prisms by the plane mirrors, it is advisable to produce the desired divergence of rays passing through the slit by means of diffraction, closing the slit until the length of the first diffraction spectrum is just equal to the diameter of the objective. In this operation the method of viewing the objective which has already been described is particularly useful. It is only necessary to observe that the middle and brightest band of the large number of bright and dark bands which are produced when the slit is slightly widened, falls centrally upon the objective. If then the slit is narrowed until only the central band remains, the eyepiece can be replaced, and the Fraunhofer lines must then appear with maximum distinctness. The desired divergence of the solar rays can also be produced by employing a concave instead of a plane mirror, but, as it seems to me, in a less advantageous manner.

I have still to describe the manner in which the annoying reflections from the two surfaces of the objective are avoided. The simplest and most effective way is to stop the reflections by suitable screens placed at the points where the images are formed, but this of course is only possible when the images are real. Whether they are real or not, and where they are situated,

depends upon the special construction of the objective, and particularly upon the relations between the curvature of the surfaces.

The objective of the instrument we are considering has a flat outer surface and a convex inner one. The image of the slit formed by the flat surface is in the plane of the slit, and by a minute inclination of the objective it can be made to fall upon the back of the slit-plate, so that with respect to any effect on the observations it is practically non-existent. Instead of inclining the whole objective it is advisable to place only the outer (plano-convex) lens slightly oblique to the optical axis, and this can be done when the two lenses are cemented together. An extremely minute prismatic displacement of the spectrum is thus produced, but as it is in the direction of the lines it has no effect whatever upon their appearance.

The other reflected image of the slit which it is necessary to consider is produced by the convex surface of the objective. It is virtual, is situated immediately behind the objective, and cannot therefore be readily suppressed. The effect of this second image, which is seen at once as a bright point of light when the objective is viewed directly, is to produce a slight, uniform illumination of the field of view. The illumination is faint, because the rays from the image are strongly divergent. This difficulty can also be remedied, either by placing a very small screen outside the eyepiece (at the position of the eye) to intercept the image, or, what appears to me to be the simpler way, by placing a drop of black varnish on the center of the objective. The latter arrangement does not have the least injurious effect on the observation of the spectral lines, and the loss of light which it causes is imperceptible.

With our apparatus, therefore, the difficulties arising from the reflection of light by the surfaces of the object glass are completely overcome.

All other false light is prevented from reaching the eye by the eyepiece cap *Oc*, a protecting screen supported by the eye end of the telescope, and a cover which goes over the prism and

the two objectives *Ob* and O_1. The last two protective devices are not shown in Figs. 5 and 6.

The application of the spectroscope described above is restricted to qualitative investigations. In order to adapt the instrument to wider fields of research (photometry, etc.) it is necessary to separate the collimator from the observing telescope. This can be done by placing an ordinary totally reflecting prism in front of the objective of the collimator tube, which is fixed at right angles to the telescope, so that the rays reflected from it are made parallel to the axis of the latter. The two tubes must now of course be placed at different heights (the

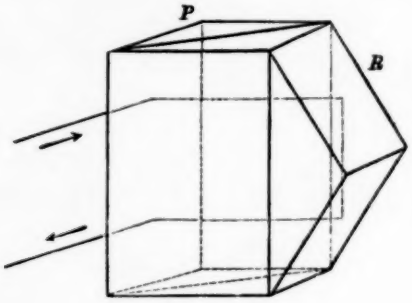

FIG. 8

distance between centers being equal to the diameter of the objectives). The prism *P* must consequently have a height equal to twice the diameter of the objectives, and the rays are transferred from one story to the other by two total reflections at the interior surfaces of the prism *R* (Fig. 8), which is cemented to the back of the large prism. This form of instrument retains in other respects all the advantages which have previously been described.

An article by A. E. Tutton on "An Instrument of Precision for producing Monochromatic Light of any desired Wave-length, and its Use in the Investigation of the Optical Properties of Crystals"[1] gives me occasion to point out that our apparatus (in both forms) can also be applied to the purposes which are there men-

[1] *Proc. R. S.* **55**, 111, 1894.

tioned, and, it seems to me, much more advantageously. It is only necessary for this purpose to cover the lower half of the field of our spectroscope with a plate, having a slit parallel to the one already in place. Such a second slit, if movable, would also be of great value for visual observations, as it would enable the observer to examine any given part of the spectrum while all other parts were excluded.

Minor Contributions and Notes.

PHOTOGRAPHIC CORRECTING LENS FOR VISUAL TELESCOPES.

Since my article on a correcting lens was printed in the February number of The Astrophysical Journal I have learned a number of interesting facts relating to the history of the subject. It seems that a lens of the form considered in my article was described by the Astronomer Royal (Mr. Christie) at a meeting of the Royal Astronomical Society on June 10, 1887; but as the lens was intended chiefly for ordinary photography of small objects, Mr. Christie withdrew his paper, with the intention of working out a combination which would give a larger field. Hence the paper was not published. Dr. Huggins saw at once, however, that the lens was just the thing for photographic work with the spectroscope, and at his request Mr. Turner computed a lens according to Mr. Christie's plan from data which Dr. Huggins furnished. The lens was made by Sir H. Grubb. Its diameter is three inches, and it is placed twenty-seven inches within the focus of the fifteen-inch refractor. The alteration of focus for the F line is only about one-quarter of an inch, which is of course immaterial, and the spectrum is practically linear from F to beyond H. It is only quite recently that this lens has been used for spectrum photography.

The discussion at the meeting of the Royal Astronomical Society is reported in the *Observatory*, **10**, 255, but as the subjects of such discussions are not indexed, it naturally escaped my attention. The theory of a correcting lens for axial pencils is so simple that I should have hesitated to print my article if I had seen even this passage in the *Observatory;* still I think the curves which I have computed are interesting, as showing what may be expected from such a lens in the case of a very large telescope.

Mr. Newall's single corrector shortens the focus of the Cambridge twenty-five-inch refractor by only about nine inches, and the convergence of the refracted cone is 1 : 10. All the observations, both visual and photographic, are made in the altered focal plane. This arrangement would be impracticable in the case of a very large refractor, as with a ratio of 1 : 10 the focus would be far within the tube.

James E. Keeler.

THE COLOR OF SIRIUS IN ANCIENT TIMES.

In a paper on "The History of the Color of Sirius," which appears in *Astronomy and Astro-Physics*, Vol. XI (for 1892) p. 376, Dr. T. J. J. See refers to Virgil's mention of the star in the *Georgics*, but seems to have overlooked two similar places in the *Æneid*. Perhaps you will allow me to supply the omission, though it does not materially affect the conclusion drawn.

The first passage is in the third book of the *Æneid*, v. 141, and runs thus: "tum steriles exurere Sirius agros," which certainly seems to suggest the idea of red flames.

The other is in the tenth book, where we read (vs. 272, 273):

> "Non secus, ac liquida si quando nocte cometæ
> Sanguinei lugubre rubent, aut Sirius ardor."

Sirius is here taken as an adjective, but the sense is clear; the comparison to the reddening light of a comet presaging slaughter shows that "ardor" conveys the idea of red light, similarly to the passage "ardebat in cœlo," quoted by Dr. See from the fourth book of the *Georgics*.

W. T. Lynn.

Blackheath, London, S. E. England, Feb. 18, 1895.

ON THE VARIABILITY OF *ES.-BIRM.* 281.

This star is Schj. 115; *Birm.* 211; BD. + 17°.1973; R. A. $8^h\ 49^m\ 45^s$; Dec. N. 17° 36′.7 (1900).

Schj. note is "Cape obs.: fine red; brick red; 8.5. T. Mayer, 380; 7. Ll. 17,576; 6.5. Chacornac; 6. Birmingham; 7 bis 7.5." Birmingham says: "Several since those quoted by Schj. from *A. N.*, 1843; color varying in different degrees of red and orange; 7–7.5." It is No. 69 of a Catalogue of "Suspected Variable Stars," communicated by W. H. St. Q. Gage, T. Read and myself to the *English Mechanic*, June 7, 1882, and subsequent numbers. The note there is 6½–8½ var. color Birmingham. It was copied by Mr. Gore into his "Catalogue of Suspected Variable Stars" (Proc. Roy. Irish Acad. **4**, No. 3) and is No. 274. The variation in color mentioned by Birmingham is dropped out and the extremes of magnitude retained. I noted in the new edition of *Birmingham* "the star is probably a variable of the 19 Piscium type." As far as I am aware the only observations from comparison stars are:

1878, Feb.	28,	7.3,	Gore.	1885, Feb.	2,	6.4, Es.
1878, Dec.	21,	7½,	"	1885, "	9,	6.8, "
1883, Nov.	22,	7½,	"	1885, "	15,	6.7, Gage.
1884, April	11,	±7,	"	1885, "	16,	6½, Gore.
1884, Dec.	20,	6.5,	Gage.	1885, "	17,	6.5, Es.
1884, "	21,	6.8,	"	1885, Mar. 15,		6.7, Gage.
1884, "	22,	7.0,	"	1885, April 14,		
1885, Jan.	3,	6.5,	"	1885, Dec.	16,	6.5, Es.
1885, "	21,	6.3,	"	1887, Jan.	29,	6.5, "

Since then, apparently, it has not been observed. Gage's observations and mine should be 1884–5, not 1881–2 as in *Es.-Birm.* The following stars are suitable for comparison stars :

A BD. + 17°.1979, $1^m\ 46^s\ f$; 5′ *s*. Mag. 6.8.
B BD. + 17°.1966, $2^m\ 10^s\ p$; 8′ *n*. Mag. 7.7.

In all my previous observations the star had been rather brighter than A, save 1882, February 9. On looking the star up with a binocular on January 26, I was much astonished at its faintness. This night was poor and the stars unsteady ; it was reobserved on January 28, 29. The following are the results :

1895, Jan. 26, ± 7.2.
1895, Jan. 28, 7.8.
1895, Jan. 29, 7.6.

These observations compared with the previous ones of mine seem to leave no doubt as to its variability. It is of type IV. T. E. Espin.

Tow Law, Darlington, January 30, 1895.

THE DISPLACEMENT OF SPECTRAL LINES CAUSED BY THE ROTATION OF A PLANET.

M. Deslandres has recently published a note (*C. R.* **120**, 417–420) on the application of Doppler's principle to the determination of the period of rotation of a planet, showing that in the case of a rotating body like Jupiter,[1] which shines by reflected light, the displacement of a line in the spectrum is twice as great as it would be if the body were self-luminous. The theory of this supposed new principle is discussed by M. Poincaré.

The principle has however long been recognized, although I am unable to say definitely by whom it was first stated. Perhaps the

[1] Supposed to be in opposition.

earliest reference to the effect of the motion of a reflector is by Niven (*M. N.* **34**, 345, 1874), who calculated the relative motion of the Earth and each of the other planets in the line of sight on the assumption of circular motion. The motion of a planet in the line of the radius vector was therefore neglected, although its effect was pointed out.

Mr. Maunder has clearly described the effect of rotation in this very case of Jupiter. He says: "The planet Jupiter, from the wonderful velocity with which it rotates, affords another means of demonstrating this displacement to the eye. The difference of motion of the two limbs is more than 15 miles per second, and the effect of this difference is doubled by the fact that Jupiter shines by reflected, not inherent light. The relative displacement therefore is equivalent to that produced by a motion of 30 miles per second, a very appreciable amount" (*Obsy.* **8**, 118, 1885).

In some photographs of the spectrum of Jupiter that I made last winter with high dispersion, the obliquity of the planetary lines is shown very beautifully. The planet was kept very accurately centered, with the slit parallel to the belts, and a solar spectrum was subsequently photographed on each side. I made no careful measurement of the inclination of the lines, as the plates were made for another purpose, but satisfied myself that it represented a difference of velocity of about 30 miles.

JAMES E. KEELER.

Dr. Pulfrich's Modification of the Littrow Spectroscope.—Although the spectroscope described in the paper by Dr. Pulfrich (translated in our present number) has little of novelty beyond the substitution of a compound half-prism for the simple half-prism of the ordinary form of Littrow spectroscope, it is carefully worked out, and is put into the practical and convenient form which is characteristic of the Zeiss workshops. For laboratory purposes requiring only a moderate dispersion it should be a useful instrument. We do not share the author's opinion as to its advantages (other than those of compactness) when a considerable dispersion is given to the apparatus by increasing the number of pieces in the compound half-prism. It would then have the same defects that make the ordinary direct-vision prism unserviceable for work requiring brightness of spectrum and good definition, namely, great thickness of glass to be traversed and comparatively small resolving power. For such work nothing can replace the prism-train of the usual form of spectroscope.

Recent Publications.

A LIST of the titles of recent publications on astrophysical and allied subjects will be printed in each number of THE ASTROPHYSICAL JOURNAL. In order that these bibliographies may be as complete as possible, authors are requested to send copies of their papers to both Editors.

For convenience of reference, the titles are classified in thirteen sections.

1. THE SUN.

BURTON-BROWN, COL. A. Notes on the coming Total Eclipse of the Sun, August 8, 1896, and Suitable Observing Stations in Norway M. N. **55,** 93–101, 1895. Jour. B. A. A. **5,** 158–163, 1895.

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2. THE SOLAR SPECTRUM, INFRA-RED, VISIBLE, AND ULTRA-VIOLET.

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SAWYER, EDWIN F. Observations of Variable Stars. A. J. No. 338, **15**, 11–13, 1895.

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NOTICE.

The scope of THE ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

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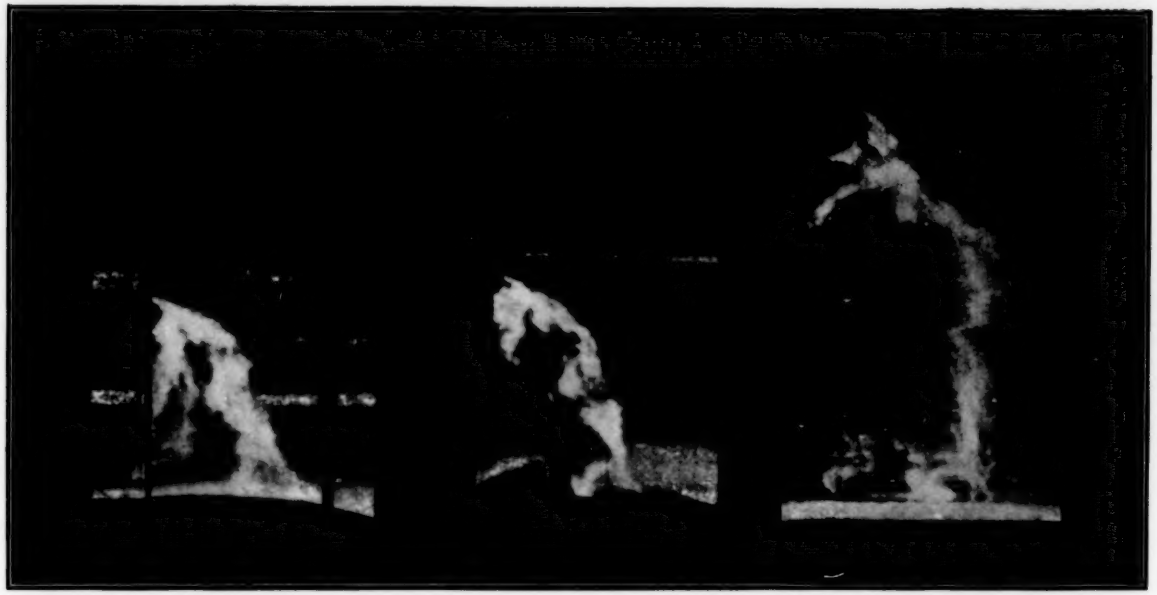
PLATE XV



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ERUPTIVE PROMINENCE PHOTOGRAPHED AT THE KENWOOD OBSERVATORY, MARCH 25, 1895